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NUCLEAR CRITICALITY SAFETY EVALUATION FOR THE CO-LOCATED STORAGE OF HEC AND NON-HEC WASTES CONTAINING FISSILE MATERIAL

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TABLE OF CONTENTS

TABLES

TABLE OF CONTENTS (Continued)

APPENDIX A

URS Calculations

* Validation Calculations

ATTACHMENTS

1.0 Introduction

This NCSE provides the criticality and contingency analyses that have been performed to support the safe packaging and storage of waste forms of fissile bearing wastes generated at the WVDP. Specifically, this analysis considers the co-located storage of waste storage containers previously evaluated separately in WVNS-NCSE-001 and WVNS-NCSE-002 as well as the storage of wastes similar to those considered in WVNS-NCSE-002, but whose dimensions do not permit storage in containers considered in that evaluation.

2.0 Description

The form of the fissile material associated with wastes considered in this evaluation is well documented in other Nuclear Criticality Safety Analyses (NCSE). WVNS-NCSE-001 evaluates generic fissile material in a generic waste matrix without assumptions regarding moderation. The requirements for waste containers in WVNS-NCSE-001 are implemented in PSR-6 and the isotope of concern is Pu^{239}. Other waste forms containing fissile material in the form of spent fuel waste are described in WVNS-NCSE-002 and implemented in PSR-18. The material of concern is unirradiated, 5% enriched U^{235}.

This document analyzes the co-location of these waste forms in storage. The analyses for each of the waste forms previously analyzed independently are stand alone. This analysis does not impose new requirements nor relax any limiting conditions described in PSR-6 and -18.

In addition, this document analyzes the packaging and storage of bulk contaminated equipment from the Head End Cells. Items such as the maintenance table, leached hull dump station and fuel head shears, are also contained in this analysis. The fissile debris contamination of this equipment is expected to be consistent with that evaluated in NCSE-002; however, the dimensions of the waste will not permit packaging in 30 gallon drums and the size reduction of these materials to allow for packaging in 30 gallon drums is not practical. Furthermore, fissile material contamination on these bulk items may exceed the fissile material mass limits provided in WVNS-NCSE-001. Consequently, the criticality safety of these wastes and their co-located storage with wastes previously evaluated in WVNS-NCSE-001 and -002 are also considered here.

3.0 Requirements Documentation

This NCSE has been developed in accordance with WVDP-162, *WVDP Nuclear Criticality Safety Program Manual*. There are no requirements unique to this evaluation.

4.0 Methodology

The calculations that provide the bases for this document were performed with KENO V.a, module in the Standardized Computer Analyses for Licensing Evaluation (SCALE), Version 4.4. KENO V.a is a multi group Monte Carlo criticality program used to calculate the k-effective (k_{eff}) of a 3 dimensional system. It will also calculate lifetime and generation time, energy dependent leakages, energy and region dependent absorptions, fissions, fluxes and fission densities.

The model can be run with a variety of geometry configurations, including non-concentric placement options. It will also permit designating 'hole' locations in models, particularly useful when describing reflectors with gaps or shipping casks. The largest restriction on KENO geometry is that no intersections of shapes is permitted. In problems of concern for the purposes of this document, all shapes are either completely contained or adjacent to one another.

KENO V.a employs supergrouping energy dependent information in the event computer memory is too small to hold all of the problem data at once. KENO V.a will determine the number of supergroups to allow problem execution. Variables subject to supergrouping include cross sections, reflector albedos, leakages, absorptions, fissions, fluxes, and weighting factors for tracking neutrons. Supergrouping allows larger problems to be run on smaller computers since individual supergroups can be moved in and out of memory as needed. If all of the problem energy dependent data can be accommodated at one time, only one supergroup is generated.

Additional data and documentation regarding the code can be found in NUREG/CR-0200, Revision 6, Volume 2, Section F 11, "KENO V.a: An Improved Monte Carlo Criticality Program with Supergrouping", published in March, 2000. To accommodate code bias and uncertainty, a subcritical k-effective limit of 0.93 was selected as the maximum threshold in assessing the nuclear criticality safety of various problem scenarios.

4.1 Previous Model Description

WVNS-NCSE-001 employed Monte Carlo N-Particle (MCNP) 4A to model the waste forms and conditions. Waste was assumed to be Pu^{239} either homogeneously distributed or as a sphere in a cellulose moderated container. The sphere location and cellulose density were adjusted to optimize neutron generation. External moderation was adjusted to range from light misting to full flooding. The containers modeled included 55 gallon drums and waste boxes of various sizes. The drums contained 200g of fissile material and the boxes modeled contained 350 g of fissile material. Various stacking heights were evaluated. The analysis indicated that storage of these containers in worst-case configuration for geometry and moderation was safe and that container stacking up to 4 tiers or 12 feet would not result in criticality. A threshold k_{eff} for the analysis was conservatively set to 0.93 to account for bias and bias uncertainty.

WVNS-NCSE-002 also utilized MCNP 4A as the modeling tool. Waste was assumed to be unirradiated, 5 weight percent enriched uranium in a hexagonal, heterogenous array. The containers were modeled as 30 gallon drums and typically contained 5% (by volume) water. Conservatively, two containers with higher water content (to increase moderation) were evaluated in the container array. External moderation was examined and the results indicated that in the event of complete flooding, a single tier configuration would remain subcritical. In the event of no external moderation, the waste could be stacked up to three tiers high without exceeding the threshold k_{eff} of 0.93.

4.2 Current Model Description

The fissile material bearing containers were assumed to be contained in a structure which was modeled as an infinite two-dimensional array with a three-foot thick concrete floor. The waste forms considered were similar to those above.

Fissile material bearing containers described in WVNS-NCSE-001 were modeled as 55 gallon drums (referred to as PSR-6 drums) or containers having dimensions similar to those of a B-25 box. The sources in the drums were assumed to be 125 g Pu^{239} spheres arranged to optimize neutron generation. The drums and boxes were typically modeled with little internal moderation, however, moderation was adjusted to determine worst case conditions. External moderation was adjusted from 0% to 100% to maximize k_{eff}. The boxes contained 200 g Pu sources, either as spheres or thin slabs (approximately 100cm x 100cm square). Source location was adjusted in the box to maximize neutron generation.

Waste forms described in WVNS-NCSE-002 were modeled as 30-gallon drums with 1920 fuel rods. The rods contain a mixture of uranium and water, with the fuel component in the form of UO_2 enriched to 5% U^{235}. One third of all rods in the drums contained UO_2 and 5% water. The remaining two-thirds of the rods contained 5% water only . In many simulations, two ‘worst case’ 30-gallon drums are present. These are PSR-18 bound collection containers. These are similar to other PSR-18 drums except the water only rods (2/3 of the total) have a net water content of 100%. These collection containers contribute to overall system k_{eff} by providing enhanced moderation characteristics. It is assumed that these collection containers are inadvertently stacked next to existing stacks of co-located containers. In some cases they are modeled as part of the co-located array, however, the limiting condition is assumed to be placement adjacent to a co-located array.

Bulk contaminated HEC waste is assumed to be solids with imbedded and surface waste particles. Examples include HiVac table components such as the table top, the table legs, or the maintenance table and motor. This bulk waste is assumed to be dry and therefore, not well moderated. Less than ideal geometry and lack of moderation effectively reduce the criticality hazard, even in the eventuality greater than 200 grams of fissile material may be present. In an analysis of this waste form, it is assumed: the container is loaded with 5% enriched U^{235} based on specific data from BUF-04-031, the container is simple steel, the contents are modeled in MicroShield v. 6.02 as rectangular parallelepiped sources, buildup is calculated using the transition space as the buildup medium, all isotopes are assumed to be held in proportion to ORIGEN data, which has been adjusted to current and future years, fissionable sources include U^{233}, U^{235}, Pu^{239}, Pu^{241}, and gamma sources are conservatively constrained to Co^{60} and Cs^{137} only.

In a parametric shielding evaluation, steel shielding thickness and distance to the source are varied and the geometry is changed. In this examination, the equivalent amount of waste in a PSR-18 bound container is placed in a 44.75 x 72 x 46 inch box for consideration.

Various geometric arrangements of containers and types were considered. Tier height was adjusted and ENDF/B-IV 27 energy group cross sections were used in these KENO calculations of k_{eff}. KENO models were executed on a Pentium 4, 3.06 GHz personal computer with a Windows XP operating system.

5.0 Discussion of Contingencies and Controls

A contingency is “a possible but unlikely change in a condition/control important to the nuclear criticality safety of a fissionable material operation that would, if it occurred, reduce the number of barriers (either administrative or physical) that are intended to prevent an accidental nuclear criticality” (DOE-STD-3007-93). Contingencies previously considered are the basis for those in this analysis.

5.1 WVNS-NCSE-001Contingencies

For containers bearing fissile material in PSR-6 bound drums and boxes, the following is excerpted from NCSE-001:

At least two of the following changes to conditions or controls would need to occur for even a very small chance of a criticality event.

(1) A significant quantity of fissile material would have to be packaged in a storage container or in multiple containers.
(2) Operations and engineering personnel would have to fail to detect that waste being packaged for storage contained a significant quantity of fissile material.
(3) A significant amount of fissile material would have to be inadvertently packaged in multiple waste containers having dimensions less than those identified in this NCSE.
(4) Waste containers would have to be stacked in a large array to an unacceptable height.

5.2 WVNS-NCSE-002 Contingencies

For wastes managed under the controls of PSR-18, the following contingencies apply:

(1) There would have to be much more fissile mass than that estimated to be present in the HECs (i.e., estimates of the fissile mass in the HECs would have to be in extreme error).

(2) Multiple containers containing significant quantities of water moderation (> 5 v/o) would have to be transported to the storage array.

5.3 Current Analysis Contingencies

In the combined analysis, several contingencies are in place to ensure that any one deviation of an assumed parameter is not sufficient to cause an inadvertent criticality.

(1) Fissile Material: Multiple waste containers would need to be packaged with fissile material far in excess of the limits prescribed in NCSE-001 and -002.

(2) Moderation: Multiple containers of waste packaged to the criteria specified in NCSE-002 would have to have internal moisture contents in excess of the volume fractions assumed in the analysis (i.e., 5 v/o).

(3) Geometry: Multiple waste containers having dimensions smaller than those evaluated in either NCSE-001 or -002 would have to be packaged with large quantities of fissile material (greater than bounds in NCSE-001, -002) and transported to the storage array.

The following table contains contingencies for PSR-6 and PSR-18 bound waste containers. The contingency and barrier is noted for each type of container. Some of these contingencies are still applicable to mixed arrays of containers. In the tables "significant quantity" with respect to fissile material refers to the minimum quantity of fissionable material for which control is required to maintain subcriticality under all normal and credible abnormal conditions (from the DOE Good Practices Guide, DOE G 421.1-1, section 3.155). "Unacceptable height" means greater than the allowed number of tiers (three for PSR-18 bound containers, four for PSR-6 bound containers) or height limit in feet (12 feet for PSR-6 bound containers).

TABLE 1	**Double Contingency Analysis for Handling and Processing Activities**	**$$=applicable to co-located array**
Contingency	**Description of Abnormal Operation or Accident Event**	**Barriers**
Fissile Mass	1. One or more HEC fissile-bearing debris containers contain a significant amount of unreprocessed, unirradiated, 5 w/o U-235-enriched fuel (i.e., contain a significant amount of evaluation basis fuel)(PSR-18)	1-1 No documented evidence of a significant loss of unreprocessed fuel to the HEC is documented in the NFS operating history, including Quarterly Reports to the AEC 1-2 Video inspection of hull debris in both the PMC and GPC indicates that a significant quantity of the hull debris in the cells has been reprocessed. No fuel can be seen in any of the video images of the hull end sections and all of the hulls viewed appear to be fully leached. 1-3 Only one campaign of unirradiated fuel (no. 14 of 26) was reprocessed by NFS. This fuel was 1.77 w/o U-235-enriched NPR fuel and represented approximately 5 percent of the total mass of uranium reprocessed by NFS. 1-4 Cell radiation measurements indicate that some, if not all, of the debris waste in the PMC and GPC have been subjected to significant neutron irradiation, in contradiction to the assumption that the fuel is unirradiated. 1-5 Only one campaign of fuel reprocessed by NFS (no. 11 of 26) had an initial U-235 enrichment in excess of 5 w/o. Operating history suggests that burnup of the fuel received by NFS would have reduced this enrichment to less than 3.4 w/o for all campaigns except campaign 11. 1-6. Operating history suggests that significant decontamination and cleanup by NFS occurred in the HECs following reprocessing, indicating that the material remaining in the HECs should not be from any particular campaign, but is due to an accumulation of wastes over several campaigns.

TABLE 1	**Double Contingency Analysis for Handling and Processing Activities**	**$$=applicable to co-located array**
Contingency	**Description of Abnormal Operation or Accident Event**	**Barriers**
Fissile Mass	2. Packaging of a significant quantity of fissile material into a single waste container or multiple waste containers. (PSR-6 containers)	2-1 Very limited number of waste streams at the WVDP contain significant quantities of fissile material. 2-2 Very high radiation rates or alpha radiation contamination levels associated with known fissile waste streams facilitate identification of significant quantities of fissile material. 2-3 **$$** Administrative controls on the maximum amount of fissile material in a waste container
Moderation	1. Multiple drums containing a significant amount of water are placed in a storage array (PSR-18)	1-1 No significant amount of moderator is believed to exist in the HECs, including the GPC sump. 1-2 **$$** Administrative controls require that drums be dried prior to transfer to storage array. 1-3 **$$** Administrative controls require that no more than 2 drums of undried waste be present in any cell at a given time.
Moderation	2. Dried drums in storage array become re-wetted due to external moderation of array.(PSR-18)	2-1 **$$** No credible potential exists for full external moderation of at-grade or above-grade cells or areas due to external surface flooding. 2-2 **$$** Extremely unlikely potential for flooding of below grade cells due to external surface flooding or due to a leak of a process line or roof leak 2-2 Storage drums provided with water-resistant HEPA filters
Moderation	3. Storage array becomes externally moderated due to flooding of array.(PSR-18)	3-1 **$$** No credible potential for flooding of at-grade or above-grade cells or areas due to external surface flooding. 3-2 **$$** Extremely unlikely potential for flooding of below grade cells due to external surface flooding or due to a leak of a process line or roof leak

TABLE 1	**Double Contingency Analysis for Handling and Processing Activities**	**$$=applicable to co-located array**
Contingency	**Description of Abnormal Operation or Accident Event**	**Barriers**
Geometry	1. Collection activities result in piling up of debris.(PSR-18)	1-1 Equipment to be used for fissile debris collection such as vacuums and clam shell scoops has been selected based on the limited potential such equipment has for piling up debris during collection. 1-2 Criticality analyses (BUF-2001-021) have shown that a hemispherical pile of fissile debris in the GPC sump is subcritical, provided that the level of moderator in the sump does not exceed the capacity of the sump (i.e., that the cell is so flooded that moderator extends into the cell - an extremely unlikely event).
Geometry	2. Material is packaged in non-critically safe waste packages (PSR-18)	2-1 Administrative controls require that HEC fissile debris waste shall be contained only in 114-liter (30-gallon) carbon steel drums.
Geometry	3. Seismic activity or operational accident results in the dislodging of a drum from a storage array, resulting in a reconfiguration of dried wastes (PSR-18)	3-1 Debris piles formed from breaching a container in such a way is only a criticality concern in those areas where significant moderator exists. 3-2 Administrative controls require that the storage of drums in the GPC be limited to single-tier arrays.
Geometry	4. Packaging of fissile material waste into containers having dimensions smaller than those assumed in the criticality evaluation. (PSR-6)	4-1 **$$** Administrative controls on fissile material waste container dimensions
Geometry	5. Stacking an array of waste containers to an unacceptable height (PSR-6)	5-1 **$$** Administrative control on height of fissile material storage array

The barriers for one container type cannot be applied to others in the mixed array (e.g. limit stacks of PSR-6 containers to 12 feet or four tiers) whereas some are type-specific (such as the barrier statement regarding storing waste in 30 gallon containers, which is only applicable to PSR-18 waste; fuel rods). Co-locating waste should not permit using one canister limitation to override the limitation for another cannister type (e.g., stacking PSR-18 bound containers to 4 tiers, the limit for PSR-6 bound containers). Only where standards are not contradictory can a limit for one be applicable for both (marked by "**$$**" in Table 1), otherwise the standard is applicable only to the type of container to which it was initially credited.

6.0 Evaluation and Results

Conditions of normal storage and packaging, abnormal storage and packaging and accident condition storage and packaging are presented for individual types of containers in WVNS-NCSE-001 and -002. Much of what is in these documents is applicable to mixed arrays. What follows is for cases considering mixed container arrays only.

6.1 Assumptions

The assumptions for mixed arrays are no different than those in the analysis for the single container analyses in WVNS-NCSE-001 and WVNS-NCSE-002 other than one new condition, that being the waste canisters are not restricted to any constraints on the ratio of PSR-6 and PSR-18 bound containers. The calculations supporting those documents are not reproduced herein, but are available. Natural phenomena assumptions, such as climate or likelihood of a seismic event, are unchanged. Concerns regarding normal and abnormal packing, handling and collecting are likewise unchanged for a mixed array. This analysis assumes that there is no vertical co-locating of wastes packaged to PSR-6 and -18 criteria.

Various ambient moisture levels were analyzed in each scenario to determine worst case conditions, from low humidity to total flooding. Generally, Pu^{239} was assumed to be in a spherical geometry, though in the worst case, Pu^{239} in a B-25 sized box was in a slab geometry. The individual container type assumptions are provided in sections 2 and 6 of WVNS-NCSE-001 and WVNS-NCSE-002 and are not reproduced here, though they are applicable. The two heavily moderated PSR-18 bound collection containers are limited to being stacked next to arrays of other containers, but not co-located with the arrays. In some models they are conservatively co-located, but this is not the binding case. PSR-18, Limiting Condition for Operation #3 states "Fissile material in a storage array shall be stored only in FISSILE MATERIAL STORAGE DRUMS", so the water saturated collection containers are not permitted to be co-located with the arrays, only be adjacent to them.

Several conditions were evaluated and the results are presented in Table 2. Diagrams of configurations are not to scale.

6.2 Results

Analysis progressed through several steps. First, only arrays of PSR-6 bound containers (drums only) and PSR-18 bound containers exclusively were analyzed. The subsequent steps were arrays of mixed containers in various configurations. Finally, arrays of PSR-6 bound boxes with PSR-18 bound drums were considered.

The worst case overall is a series of 4 PSR-6 bound boxes surrounded on the perimeter with PSR-18 bound FISSILE MATERIAL STORAGE DRUMS and a pair of water heavy PSR-18 bound collection containers sandwiched between low water content PSR-18 FISSILE MATERIAL STORAGE DRUMS. The boxes contain Pu slabs facing the water heavy PSR-18 collection containers. Slabs and spheres were both tested in the boxes with slabs providing slightly higher reactivity. The moisture within PSR-6 bound boxes was varied and the reactivity decreased as water content in the boxes rose past 5 v/o, the estimate in the worst case. The inner and outer drums are stacked three high with the number of PSR-6 bound boxes four tiers high. The resulting four box tier $k_{eff} + 2\,\sigma$ is 0.9283. This configuration is overly conservative since the collection containers are within the storage array and is beyond the limitations and controls imposed by PSR-6. In Table 2, see the example named 'Box' for an illustration and additional details.

The worst case with PSR-18 bound collection containers adjacent to the arrays of mixed waste in accordance with PSR-6 results in a $k_{eff} + 2\sigma$ of 0.9112. In Table 2, see the example named ‘8Ballodd’ for an illustration and additional details. The Pu spheres in the PSR-6 bound drums are positioned so that 8 spheres are as close as possible in the center of the array. The spheres in the ground level row are at the top, positioned to the center of the overall array. The second layer of drums’ spheres are at the bottom of the drums positioned to the center. A similar arrangement applies to the third and fourth tiers.

Results indicate there are potential inconsistencies. These are readily explainable. For example, in the trials labeled ‘East’ and ‘Easodd4', the k_{eff} decreases then rises again as tiers (and fissile mass) increase. This may be a function of the moisture optimization. Ambient moisture steps are in 10% blocks. More refined steps would smooth out the curve, but since the effect is small overall and in no case is the limit of 0.93 approached, this approximation is acceptable for the purposes of this analysis. Another possible cause is that almost all of the additional containers act as weakly moderated absorbers and as the arrangement expands, critical geometry is actually more difficult to achieve.

The likelihood of certain abnormal or accident conditions are no worse for a mixed array than separated containers (e.g. fire, earthquake, roof collapse). The severity of these events are not worsened by co-locating the waste containers, i.e. a fire would not be more likely to spread by having a PSR-18 container with PSR-6 containers. A roof collapse would be subject to the same unlikely probability of occurrence, the same mitigating factors, and the same specific geometry and moderation characteristics.

The integration of the analysis of bulk HEC waste into the current analysis was accomplished by considering the form and amount of contamination expected to be present on these wastes and comparing those assumptions to those evaluated in WVNS-NCSE-001 and WVNS-NCSE-002.

Bulk HEC wastes (such as the fuel head shears in the PMC) are assumed to be contaminated with fissile materials similar to those considered in WVNS-NCSE-002. While it is possible that the extent of the contamination may exceed the fissile material mass limit for waste containers established in WVNS-NCSE-001 (i.e., 200g), it is not expected that the amount of fissile material contamination will exceed the amount assumed to be present in a FISSILE MATERIAL STORAGE DRUM evaluated in WVNS-NCSE-002 (approximately 9,800g). An array containing boxes of bulk contaminated equipment from the Head End Cells will therefore be more critically safe than a similar array containing FISSILE MATERIAL STORAGE DRUMS if it can be shown that the amount of fissile material contamination in the waste box is less than that assumed to be present in a FISSILE MATERIAL STORAGE DRUM and if the dimensions of the waste storage box are greater than those of a FISSILE MATERIAL STORAGE DRUM. The improvement in criticality safety is due to the reduced concentration of fissile material in the storage array. Therefore, the packaging of bulk Head End Cell components in waste boxes and the subsequent transfer of those waste boxes to a storage array containing wastes packaged to the criteria of either WVNS-NCSE-001 or WVNS-NCSE-002 will be safe provided that the box contains less than 9,800 g of fissile material and the smallest dimension of the waste box exceeds the greatest dimension of a FISSILE MATERIAL STORAGE DRUM.

A Dames & Moore report from Feb, 1994 by Y.C. Yuan details the criticality concerns for waste streams at West Valley in the vitrification process. The report states that all components, including the CFMT (concentrator feed make up tank), the MFHT (melter feed hold tank), the SFCM (slurry fed ceramic melter) and HLW (high level waste) canisters are determined to be subcritical systems under both normal and abnormal conditions. At maximum expected fissile material concentrations and loading, the k_{eff} (effective neutron multiplication factor) was determined to be less than 0.1 in 95% of cases. KENO V.a was used in this analysis. The CFMT was determined to potentially present the highest k_{eff} since it has the highest fissile material concentration and loading. In the analysis, atomic densities were derived based on an incidental double batching of the HLW slurry feed. The waste was compared to Nuclear Safety Guide Limits and the cumulative estimated fissile material loading was over an order of magnitude lower than the subcritical limit for the most limiting nuclide, Pu^{239}.

This was broken down concisely in a memo from J. Wolniewicz in Jan. 1994, which concluded that criticality is not a credible event. Table 3 in that memo shows that in no instance, for steps in the vitrification process stream, did fissile material limits come within even an order of magnitude of Nuclear Safety Guide limits.

WVNS-SAR-001 Rev 9, 8.7.3.4, Criticality Concerns During Waste Package Handling and Transport, refers to the Yuan report. WVNS-SAR-003 Rev 8 refers to the Wolniewicz report and states "...even with maximum concentration and optimum moderation and reflection, an additional increase in concentration by greater than a factor of 20 would be necessary in order to exceed the criticality limits."

Vitrification wastes provide little in the way of neutron multiplication. The silica in the glass has a slightly higher thermal neutron absorption cross section than iron. The presence of boron further reduces the thermal non-leakage factor, making criticality less likely. Two optimally moderated PSR-18 bound waste canisters (k_{eff} =0.85) can be placed immediately adjacent (i.e., no separation) to stacks of PSR-6 bound drums stacked four tiers high. Furthermore, a perfect reflector was assumed on 4 sides of the array and a concrete floor under the array. Placing vitrification waste products, with a k_{eff} of less than 0.1, adjacent to other waste forms (PSR-6 bound wastes) would not constitute a criticality hazard. These vitrification product containers would have less favorable moderation, reflection, concentrations and loading than the moderated PSR-18 bound containers.

7.0 Design Features and Administratively Controlled Limits and Requirements

Design features and limits for containers analyzed in WVNS-NCSE-001 are expressed within that document and PSR-6. Similarly, for waste forms analyzed within WVNS-NCSE-002, design features and limits are contained within that document and PSR-18. None of those design features or limits is altered in this analysis. This analysis does not replace or supercede any features or limits in NCSE-001 and -002.

A point of clarification is necessary regarding stacking limit differences for containers bound by PSR-6 and -18. The PSR-6 (drums and boxes) limit for stacking is four tiers or 12 feet. The PSR-18 stacking limit for an array of containers located outside of the GPC is three tiers. For container arrays of different types stacked adjacent to one another it is necessary to ensure that these separate stacking limits are preserved. In the various KENO runs for the current evaluation, four tiers was frequently used for PSR-18 bound waste containers for conservatism and the system was found critically safe.

Horizontal configurations of containers in any configuration are not criticality hazards. This analysis explicitly considered stacks of PSR-6 bound containers next to PSR-18 bound containers. This document does not make any assertions regarding vertical layering, i.e. a layer of PSR-6 bound waste on top of a layer of PSR-18 bound waste. It has not evaluated all possible configuration of vertical arrays.

In the event that PSR-6 and PSR-18 drums were stacked in mixed vertical layers, it is expected the array would remain subcritical. Typically, PSR-6 bound drums contribute less reactivity to an array and interspersing them with an array of PSR-18 bound drums is not expected to create a criticality hazard. The highest reactivity conditions evaluated in this set of models came from co-locating PSR-18 bound FISSILE MATERIAL STORAGE DRUMS and PSR-6 bound collection containers with PSR-6 bound boxes. Vertical mixing of PSR-6 and PSR -18 bound containers were not analyzed nor was co-locating with more than 2 water saturated PSR-18 bound drums.

Bulk equipment from the HECs that contains > 1g of fissile material and that require storage in a container that is greater in size than a 30 gallon drum may be stored in a waste storage box provided: 1) the smallest dimension of the waste storage box is greater than 29 inches (i.e. the greatest dimension of a FISSILE MATERIAL STORAGE DRUM as defined in WVDP-218; 2) the fissile contaminated materials originated in the HECs (to preserve the assumption regarding fissile nuclide ratios assumed in WVNS-NSCE-002; 3) the mass of fissile material in the box remains below 9800 g (the equivalent amount of fissile material evaluated in a FISSILE MATERIAL STORAGE DRUM in WVNS-NCSE-002; 4) the amount of water or water-equivalent moderator in the box does not exceed 1.5 gallons (corresponding to 5 volume percent in a 30 gallon drum; and 5) the boxes are not stacked more than three tiers high. Boxes containing these bulk contaminated items may be co-located with arrays of containers that have been packaged to meet the criteria of PSR-6 or PSR-18. In general, analyses performed to establish the criticality safety of PSR-18 containers are valid for these waste boxes.

8.0 Summary and Conclusions

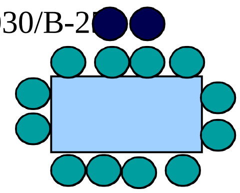
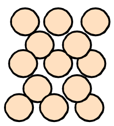
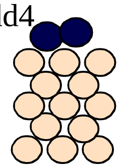
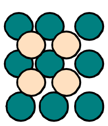
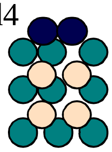
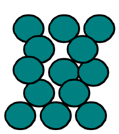
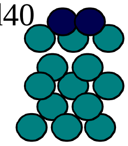
The analysis of multiple combinations of co-located PSR-6 and PSR-18 bound waste containers accounted for various numbers of source types, geometries of sources within the containers, geometry of containers themselves, ambient moisture levels and number of tiers. Fissile material inventories within containers typically fall well below the limits, however the limit values are both: 1) used to be conservative and 2) conservatively evaluated with two adjacent water saturated PSR-18 bound collection containers. Waste stacking limitations remain at three tiers for PSR-18 bound waste containers and four tiers for PSR-6 bound waste containers. In no case examined, even with several scenarios of four tiers of waste material, did the k_{eff} value for an array of containers exceed 0.93.

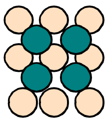
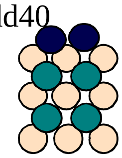
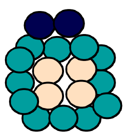
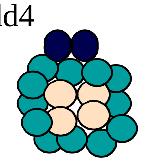
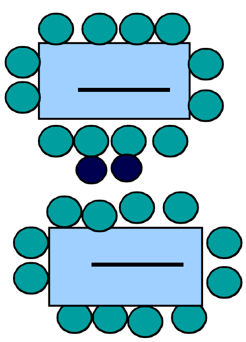
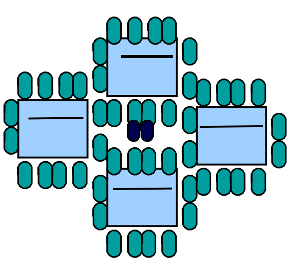
Spacing between adjacent containers of different types was minimized in the analysis (direct container to container contact) and found to be critically safe. This demonstrates a specific adjacent spacing requirement between containers of different types may be removed. The packaging of bulk Head End Cell components in waste boxes and the subsequent transfer of those waste boxes to a storage array containing wastes packaged to the criteria of either WVNS-NCSE-001 or WVNS-NCSE-002 will be safe provided that the box contains less than 9,800 g of fissile material and the smallest dimension of the waste box exceeds the greatest dimension of a FISSILE MATERIAL STORAGE DRUM.

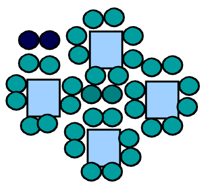
The analysis methodology and conservatism of the analysis ensures that in the event there is colocation of waste containers, there is adequate protection and margin to avoid criticality. This assertion applies to storage and handling evolutions. The container array will remain subcritical under all credible accident and abnormal conditions as well as under all normal conditions.

TABLE 2 Selected Example Models and Results

Note 1: PSR-6 drum or box source assumed to be Pu^{239} sphere in center of container unless noted
Note 2: PSR-6 box has B-25 box dimensions unless noted

Calc/Case (BUF-04-### + file prefix)	#PSR-6	#PSR-18	# PSR-18 H_2O sat	# PSR-6 box	# tiers	Ambient ρ (H_2O)	$K_{eff}+2\sigma$
030/B-2 	0 12	12 0	2 2	1 1	1 1	1.0 1.0	0.8753 0.8403
027/East 	13 26 39 52				1 2 3 4	0.5 0.3 0.3 0.1	0.1671 0.1685 0.0677 01692
027/Easodd4 	13 26 39 52		2 2 2 2		1 2 3 4	1.0 1.0 1.0 1.0	0.9063 0.9035 0.9070 0.9061
028/North 	4 8 2 16	9 18 27 36			1 2 3 4	0.3 0.2 0.2 0.2	0.5178 0.6211 0.6557 0.6791
028/Norodd4 	4 8 12 16	9 18 27 36	2 2 2 2		1 2 3 4	0.3 0.3 0.3 0.3	0.8908 0.8867 0.8940 0.8909
027/West 		13 26 39 52			1 2 3 4	0.4 0.3 0.3 0.3	0.6823 0.7588 0.8256 0.8360
027/Wesodd40 		13 26 39 52	2 2 2 2		1 2 3 4	0.3 0.3 0.3 0.3	0.8866 0.8929 0.8900 0.8843

Calc/Case (BUF-04-### + file prefix)	#PSR-6	#PSR-18	# PSR-18 H_2O sat	# PSR-6 box	# tiers	Ambient ρ (H_2O)	$K_{eff}+2\sigma$
028/South 	9 18 27 36	4 8 12 16			1 2 3 4	1.0 0.4 0.4 0.3	0.4233 0.4817 0.5034 0.5208
028/Sthodd40 	9 18 27 36	4 8 12 16	2 2 2 2		1 2 3 4	1.0 0.4 0.4 0.3	0.8700 0.8939 0.8826 0.8865
028/8Ballodd 	8 16 Pu not in radial center of drum, but closest to center of array	24 36	2 2		2 4	0.2 0.2	0.9183 0.9190
029/Oddodd4 	4 8 12 16	12 24 36 48	2 2 2 2		1 2 3 4	0.3 0.3 0.3 0.3	0.9147 0.9121 0.9128 0.9115
030/B25slab1 		24 48 72 72	2 2 2 2	2 4 6 8 each with 100x100 cm slab, 200 g Pu^{239}, centered	1 2 3 4	0.3 0.3 0.3 0.3	0.8996 0.9092 0.9108 0.9112
030/Box*** 		100 148 148 148	2 2 2 2	8 8 12 16	x/y/z 2/2/3 3/2/3 3/3/3 3/4/3	0.3 0.3 0.3 0.3	0.9231 0.9228 0.9263 0.9283

Calc/Case (BUF-04-### + file prefix)	#PSR-6	#PSR-18	# PSR-18 H_2O sat	# PSR-6 box	# tiers	Ambient ρ (H_2O)	$K_{eff}+2\sigma$
031/TN 		102 102 102	0 2 2	16 16 16$^{\&}$ small box, 30 inch cube.	3/4/1 3/4/1 3/4/1	0.3 0.3 0.3	0.8443 0.8770 0.8796

*** in these trials, there are always 3 tiers of PSR-18 bound containers in the central volume. In the “Box” trials, there is a layer of 2 high water drums sandwiched between 4 low water drums. In the last 3 cases of “Box”, the Pu slabs in the boxes at 3 and 9 o’clock are parallel and adjacent to the end of the box closest to the high water density drums. Furthermore, the PSR-18 bound drums along the perimeter of each box are stacked only 3 tiers high in the case where boxes are 4 tiers high.

x/y/z = # non moderated drum tiers / # box tiers / # of tiers which one tier is moderated

“&” indicates double fissile mass (approx. 400 g)

9.0 References

9.1 WVNS-NCSE-001, Rev 0, Nuclear Criticality Safety Evaluation for the Packaging and Storage of Fissile-Bearing Wastes at the WVDP, 11/06/01

9.2 WVNS-NCSE-002, Rev 0, Nuclear Criticality Safety Evaluation for the Packaging and Storage of Fissile-Bearing Debris in the Head End Cells, 5/07/02

9.3 PSR-6, Rev. 2, Process Safety Requirement, Fissile Material Packaging and Storage Requirements, 6/12/02

9.4 PSR-18, Rev 0, Process Safety Requirement, Collection, Processing and Storage Requirements for Fissile Material from the Head End Cells, 6/12/02

9.5 NUREG/CR-0200, Rev 6, Vol 2, Section F11, KENO V.a: An Improved Monte Carlo Criticality Program with Supergroups, Mar. 2000

9.6 WVDP-218, Rev 13, Process Safety Requirements; Preface for Process Safety Requirements, 12/17/03.

9.7 DOE G 421.1-1, DOE Good Practices Guide, Criticality Safety Good Practices Guide for DOE Nonreactor Nuclear Facilities, 8/25/99.

9.8 Dames & Moore technical memorandum, Criticality Evaluation: WVDP Vitrification Process Systems, Y. C. Yuan, Feb 7, 1994.

9.9 Dames & Moore technical memorandum, Evaluation of Fissile Material Concentrations in WVDP Vitrification Facility Feed Solutions, J. Wolniewicz, Jan 30, 1994.

9.10 WVDP-SAR-001, Rev 9, Safety Analysis Report for Waste Processing and Support Activities, Mar. 08, 2004

URS

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Calculation Cover Page

Job No: **39399976 / 06354** Calculation No: **BUF-04-027/Rev. 0** Date: **February 27, 2004**

DRUM BASE CASES

Problem Statement & Calculation Objectives: Criticality Calculations were performed to determine if there was a criticality problem when various types of PSR06 and PSR18 containers were commingled.

KENO Inputs and Outputs are on a CD entitled 'NCSE-007'. The worst cases are listed in attachments 2 and 3.

Four different groupings or commingling arrays are investigated. East, East ODD, West, and West ODD. Under each group the assumptions, model description, and results are related. Individual container geometries and compositions are covered in Attachment 1.
Assumptions and some description for internal components are covered in Attachment 1 to prevent repetitions.

Group 027. PSR06 55gal drums predominant intermingled with PSR18 30gal drums. Referred to as EAST* cases.

Subgroup 027A - Case EAS1000, ...* all PSR06 drums, no PSR18 drums

<u>**Assumptions**</u>

Geometry - from 1-4 tiers of 13 PSR06 drums

Fissile Mass/Concentration - with 125g Pu-239 centered sphere in each drum in the form of PuO_2.

Reflection/Moderation - Damp air around drums - density optimized to .5 g/cm3 H2O for 1 tier
.3 g/cm3 H2O for 2 and 3 tiers
.1 g/cm3 H2O for 4 tiers
The moisture in the PSR06 drums is optimized at .05 g/cm3 H2O.

Additional Reflection - Neutronics albedo mirrored in the x and y directions to approach an infinite array.

Spacing/Interaction - drums touching and tiers touching. Did not take credit for any pallet spacing.

Enrichment - 100% enriched Pu-239

<u>**Model Description**</u>

The model evaluated 13 PSR06 drums in close-packed array with each drum containing the PSR-6 limit as shown in the figure below. The configuration is assumed to be infinite in the x and y dimensions. The drums are stacked four tiers high.

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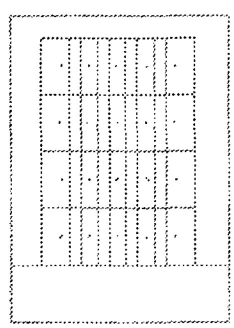
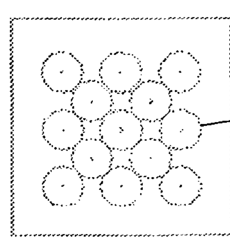
East

		k_{eff}	Sigma	k+2Sigma
1 tier	**EAS1000**			
Commingling of 13 PSR06 Drums		**0.1639**	**.0016**	**0.1671**
2 tier	**EAS2000**			
Commingling of 26 PSR06 Drums		**0.1657**	**.0014**	**0.1685**
3 tier	**EAS3000**			
Commingling of 39 PSR06 Drums		**0.1659**	**.0009**	**0.1677**
4 tier	**EAS4000**			
Commingling of 52 PSR06 Drums		**0.1676**	**.0008**	**0.1692**

EAS4000.WPD



Surrounded by
Water
Worst Case
1 tier ρ = 0.5
2 tiers ρ = 0.3
3 tiers ρ = 0.3
4 tiers ρ = 0.1



13 per tier
PSR06 55gal Drum
With Sphere of PuO_2
w/125g Pu-239
at center of drum
air inside
(optimum density = .05)

URS

Sheet No. 3/
Calc. No. BUF-04-027
Rev. No. 0

Group 027. PSR06 55gal drums predominant. Referred to as EAST* cases.

Subgroup 027B - Case EASODD1, ...* all PSR06 drums, two PSR18 moderated drums

Assumptions

Geometry - from 1-4 tiers of 13 PSR06 drums

Fissile Mass/Concentration - with 125g Pu-239 centered sphere in each PSR06 drum in the form of PuO_2.

Reflection/Moderation - Damp air around drums - density optimized to 0.5 g/cm3 H2O for 1 tier
0.3 g/cm3 H2O for 2 and 3 tiers
0.1 g/cm3 H2O for 4 tiers
The moisture in the moderated PSR18 water rods is optimized at 100% water.
The moisture in the PSR06 drums is optimized at .05 gm/cm3.

Additional Reflection - Neutronics albedo mirrored in the x and y directions to approach an infinite array.

Spacing/Interaction - drums touching and tiers touching. Did not take credit for any pallet spacing.

Enrichment - 100% enriched Pu-239

Model Description

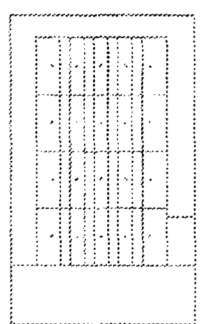
The model evaluated 13 PSR06 drums in close-packed array with each drum containing the PSR-6 limit as shown in the figure below. Two PSR18 moderated drums are permitted to touch the PSR06 array. The configuration is assumed to be infinite in the x and y dimensions. The PSR06 drums are stacked four tiers high.

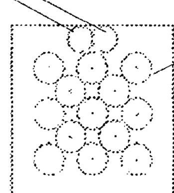
URS

EASODD4

		k_{eff}	Sigma	k+2Sigma
1 tier	**EASODD1**			
Commingling of 13 PSR06 plus 2 bad PSR18 Drums		**0.9029**	**.0017**	**0.9063**
2 tiers	**EASODD2**			
Commingling of 26 PSR06 plus 2 bad PSR18 Drums		**0.8995**	**.0020**	**0.9035**
3 tiers	**EASODD3**			
Commingling of 39 PSR06 plus 2 bad PSR18 Drums		**0.9032**	**.0019**	**0.9070**
4 tiers	**EASODD4**			
Commingling of 52 PSR06 plus 2 bad PSR18 Drums		**0.9025**	**.0018**	**0.9061**

EASODD4.wpd





URS

Group 027. PSR18 30gal drums predominant. Referred to as WEST* cases.

Subgroup 027C - **Case WES1000**, ...* all PSR18 drums, no PSR06 drums

Assumptions

Geometry - from 1-4 tiers of 13 PSR18 drums

Fissile Mass/Concentration - with 640 fuel rods (U(5)O_2) and 1280 water rods in each PSR18 drum

Reflection/Moderation - Damp air around drums - density optimized to .4 g/cm3 H2O for 1 tier
.3 g/cm3 H2O for 2, 3, and 4 tiers

Additional Reflection - Neutronics albedo mirrored in the x and y directions to approach an infinite array in two directions.

Spacing/Interaction - drums touching and tiers touching. Did not take credit for any pallet spacing.

Enrichment - 5 weight % U-235

Model Description

The model evaluated 13 PSR18 drums in close-packed array with each drum containing the worst configuration thinkable as shown in the figure below. i.e., 640 fuel rods containing U(5)O2 and 1280 water rods containing .05% water. The configuration is assumed to be infinite in the x and y directions. The drums are stacked four tiers high even though NCSE-002 limits stacking to three tiers.

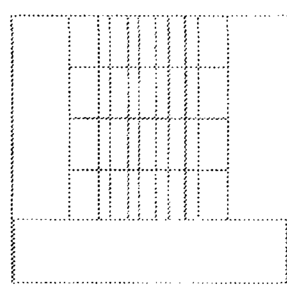
URS

Sheet No. 6/
Calc. No. BUF-04-027
Rev. No. 0

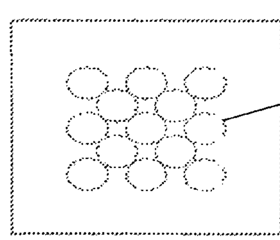
West

		k_{eff}	Sigma	k+2Sigma
1 Tier	**WES1000**			
Commingling of 13 PSR18 Drums together		**0.6785**	**.0019**	**0.6823**
2 Tier	**WES2000**			
Commingling of 26 PSR18 Drums together		**0.7568**	**.0010**	**0.7588**
3 Tier	**WES3000**			
Commingling of 39 PSR18 Drums together		**0.8222**	**.0017**	**0.8256**
4 Tier	**WES4000**			
Commingling of 52 PSR18 Drums together		**0.8326**	**.0017**	**.8360**

Wes4000.wpd



Surrounded by H2O
Worst case
1 tier ρ= 0.40
2, 3, & 4 tiers ρ = 0.30



13 per tier
PSR18 30gal
Drum with
1920 rods each
(640 $U(5)O_2$ &
1280 H2O ρ=.05)

URS

Group 027. PSR18 30gal drums predominant. Referred to as WEST* cases.

Subgroup 027D - Case WESODD, ...* all PSR18 drums, no PSR06 drums

Assumptions

Geometry - from 1-4 tiers of 13 PSR18 drums plus two moderated PSR18 drums

Fissile Mass/Concentration - with 640 fuel rods ($U(5)O_2$) and 1280 water rods in each PSR18 drum

Reflection/Moderation - Damp air around drums - density optimized to .3 g/cm3 H2O for 1,2 ,3, or 4 tiers

The moisture in the moderated PSR18 water rods is 100% water.

Additional Reflection - Neutronics albedo mirrored in the x and y directions to approach an infinite array in two directions.

Spacing/Interaction - drums touching and tiers touching. Did not take credit for any pallet spacing.

Enrichment - 5 weight % U-235

Model Description

The model evaluated 13 PSR18 drums in close-packed array with each drum containing the worst configuration thinkable as shown in the figure below. i.e., 640 fuel rods containing U(5)O2 and 1280 water rods containing .05 water. Two moderated PSR18 drums (640 fuel rods containing U(5)O2 and 1280 water rods containing 100% water) are placed touching the array. The configuration is assumed to be infinite in the x and y directions. The drums are stacked four tiers high even though NCSE-002 limits stacking to three tiers.

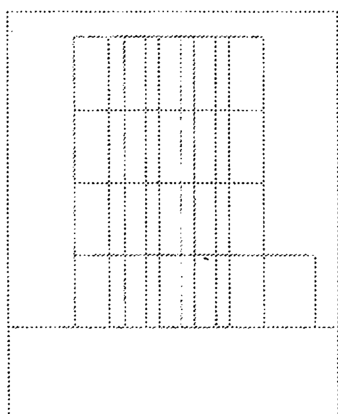
URS

Sheet No. 8/
Calc. No. BUF-04-027
Rev. No. 0

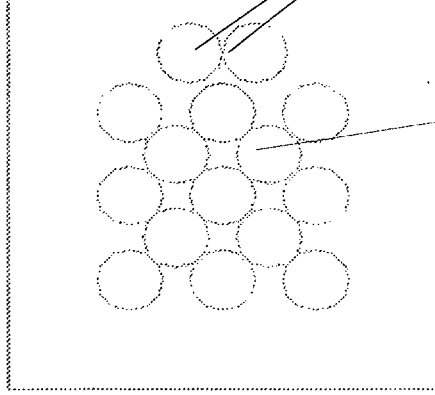
WESODD40

		k_{eff}	Sigma	k+2Sigma
1 tier	WESODD10			
Commingling of 13 PSR18 Drums plus 2 moderated PSR18 Drums		0.8814	.0026	0.8866
2 tier	WESODD20			
Commingling of 26 PSR18 Drums plus 2 moderated PSR18 Drums		0.8887	.0021	0.8929
3 tier	WESODD30			
Commingling of 39 PSR18 Drums plus 2 moderated PSR18 Drums		0.8860	.0020	0.8900
4 tier	WESODD40			
Commingling of 52 PSR18 Drums plus 2 moderated PSR18 Drums		0.8807	.0018	0.8843

WESODD40.WPD



Surrounded by Water
Worst Case
1 tier ρ = 0.3
2 tiers ρ = 0.3
3 tiers ρ = 0.3
4 tiers ρ = 0.3



URS

Group 027. PSR18 30gal drums predominant. Referred to as JOE3* cases.

Subgroup 027E - Case JOE3, ...* all PSR18 drums, no PSR06 drums

Assumptions

Geometry - one tier of 2 moderated PSR18 drums

Fissile Mass/Concentration - with 640 fuel rods ($U(5)O_2$) and 1280 water rods in each PSR18 drum

Reflection/Moderation - Damp air around drums - density optimized to .3 g/cm3 H2O

The moisture in the moderated PSR18 water rods is 100% water.

Additional Reflection - Neutronics albedo mirrored in the x and y directions to approach an infinite array in two directions.

Spacing/Interaction - drums touching.

Enrichment - 5 weight % U-235

Model Description

The model evaluated 2 PSR18 drums touching with each drum containing the worst credible configuration as shown in the figure below. i.e., 640 fuel rods containing U(5)O2 and 1280 water rods containing water with density of 1.0. The configuration is assumed to be infinite in the x and y directions.

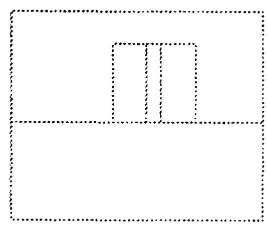
URS

Sheet No. 10/
Calc. No. BUF-04-027
Rev. No. 0

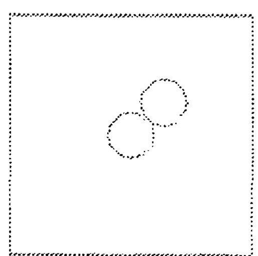
JOE3

1 tier	JOE3	k_{eff}	Sigma	k+2Sigma
2 moderated PSR18 Drums		0.8416	.0018	0.8452

Surrounded by
Water
Worst Case
ρ = 0.3



2 flooded drums on
bottom tier
PSR18 30gal Drums
with 1920 rods each
(640 $U(5)O_2$ &
1280 H_2O ρ=1.0)



URS

Sheet No. 11/
Calc. No. BUF-04-027
Rev. No. 0

References and Data Available:

1. Scale 4.4 Manual
2. PSR-6
3. PSR-18
4. NCSE-001
5. NCSE-002
6. Validation reports in BUF Calc file

Design Criteria: See WVDP-162

Assumptions: See individual Cases and Attachments

Prepared by: C Alvin Sweet — Signature — 3-11-04 — Date

Checked by: Russell Dunham — Signature — 3-12-04 — Date

Approved by: Joseph C. Wolniewicz — Signature — 05/11/04 — Date

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Calculation Cover Page

Job No: **39399976 / 06354** Calculation No: **BUF-04-028/Rev. 0** Date: **February 27, 2004**

MIXED DRUMS

Problem Statement & Calculation Objectives: Criticality Calculations were performed to determine if there was a criticality problem when various types of PSR06 and PSR18 containers were commingled.

KENO Inputs and Outputs are on a CD entitled 'NCSE-007'. The worst case is listed in Attachment 2.

Four different groupings or commingling arrays are investigated. North, North ODD, South, and South ODD. Under each group the assumptions, model description, and results are related. Individual container geometries and compositions are covered in Attachment 1.
Assumptions and some description for internal components are covered in Attachment 1 to prevent repetitions.

Group 028. PSR18 30gal drums predominant intermingled with PSR06 55gal drums. Referred to as NORTH* cases.

Subgroup 028A - Case NOR1000, ...* mostly PSR18 drums, some PSR06 drums

Assumptions

Geometry - from 1-4 tiers of 9 PSR18 drums with 4 unmoderated (.05%H_2O) PSR18 drums

Fissile Mass/Concentration - with 640 fuel rods ($U(5)O_2$) and 1280 water rods in each PSR18 drum and with 125g Pu-239 centered sphere in each PSR06 drum in the form of PuO_2.

Reflection/Moderation - Damp air around drums - density optimized to .3 g/cm3 H2O for 1 tier and 0.2 for 2, 3, and 4 tiers
The moisture in the PSR06 drums is optimized at .05 g/cm3.

Additional Reflection - Neutronics albedo mirrored in the x and y directions to approach an infinite array in two directions.

Spacing/Interaction - drums touching and tiers touching.

Enrichment - PSR06 55gal drums - 100% enriched Pu-239,
PSR18 30gal drums - 5 weight % U-235

Model Description

The model evaluated 9 PSR18 drums in close-packed array with 4 unmoderated PSR06 drums. Each PSR06 drum contains the PSR-6 limit as shown in the figure below. The configuration is assumed to be infinite in the all directions. The drums are stacked four tiers high.

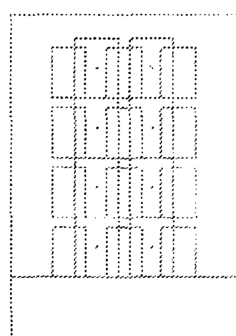
URS

Sheet No. 2/
Calc. No. BUF-04-028
Rev. No. 0

North

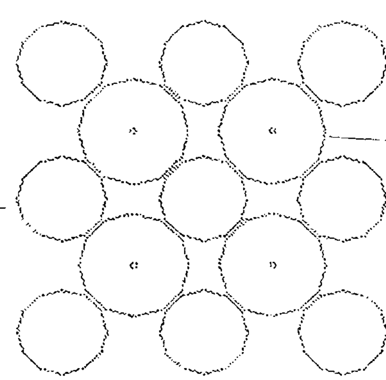
		k_{eff}	Sigma	k+2Sigma
1 tier	**NOR1000**			
Commingling of 4 PSR06 & 9 PSR18 Drums		**0.5154**	**.0012**	**0.5178**
2 tier	**NOR2000**			
Commingling of 8 PSR06 & 18 PSR18 Drums		**0.6175**	**.0018**	**0.6211**
3 tier	**NOR3000**			
Commingling of 12 PSR06 & 27 PSR18 Drums		**0.6527**	**.0015**	**0.6557**
4 tier	**NOR4000**			
Commingling of 16 PSR06 & 36 PSR18 Drums		**0.6767**	**.0012**	**0.6791**

NOR4000.WPD



Surrounded by Water
Worst Case
(Water density = 0.2) 2, 3, and 4 tiers
(Water density = 0.3) 1 tier

Nine per Tier
PSR18 30gal Drum
Full of Fuel Rods
1/3 $U(5)O_2$
water (ρ = 0.05)
2/3 water
water (ρ = 0.05)



Four per Tier
PSR06 55gal Drum
With Sphere of PuO_2
w/125g Pu-239
Air inside density opt
at .05 g/cm3.

URS

Group 028. PSR18 30gal drums predominant intermingled with PSR06 55gal drums. Referred to as NORTH* cases.

Subgroup 028B - Case NORODD1, ...* mostly PSR18 drums, some PSR06 drums

Assumptions

Geometry - from 1-4 tiers of 9 PSR18 drums with 4 unmoderated (.05%H_2O) PSR18 drums plus two moderated PSR18 30gal drums.

Fissile Mass/Concentration - with 640 fuel rods ($U(5)O_2$) and 1280 water rods in each PSR18 drum and with 125g Pu-239 centered sphere in each PSR06 drum in the form of PuO_2.

Reflection/Moderation - Damp air around drums - density optimized to .3 g/cm3 H2O for all tiers. The moisture content of the water rods in the two moderated PSR18 drums is optimized at100% water. The moisture in the PSR06 drums is optimized at .05 g/cm3.

Additional Reflection - Neutronics albedo mirrored in the X AND Y directions to approach an infinite array.

Spacing/Interaction - drums touching and tiers touching.

Enrichment - PSR06 55gal drums - 100% enriched Pu-239,
PSR18 30gal drums - 5 weight % U-235

Model Description

The model evaluated 9 PSR18 drums in close-packed array with 4 unmoderated PSR06 drums . Each PSR06 drum contains the PSR-6 limit as shown in the figure below. The configuration is assumed to be infinite in two dimensions. The drums are stacked four tiers high.

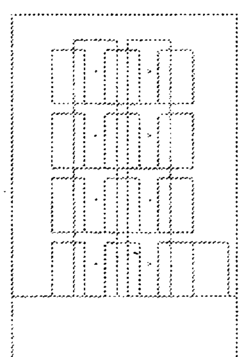
URS

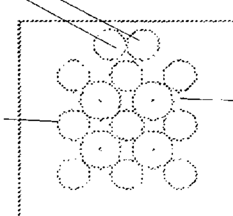
Sheet No. 4/
Calc. No. BUF-04-028
Rev. No. 0

NORODD4

	k_{eff}	Sigma	k+2Sigma
1 tier NORODD1			
Commingling of 4 PSR06 and 9 PSR18 Drums plus 2 bad PSR18 Drums	0.8842	.0033	0.8908
2 tiers NORODD2			
Commingling of 8 PSR06 and 18 PSR18 Drums plus 2 bad PSR18 Drums	0.8829	.0019	0.8867
3 tiers NORODD3			
Commingling of 12 PSR06 and 27 PSR18 Drums plus 2 bad PSR18 Drums	0.8904	.0018	0.8940
4 tiers NORODD4			
Commingling of 16 Odd PSR06 and 36 PSR18 Drums plus 2 bad PSR18 Drums	0.8875	.0017	0.8909

NORODD4.wpd





URS

Sheet No. 5/
Calc. No. BUF-04-028
Rev. No. 0

Group 028. PSR06 55gal drums predominant intermingled with PSR18 30gal drums. Referred to as SOUTH* cases.

Subgroup 028C - Case STH1000, ...* mostly PSR06 drums, some PSR18 drums

Assumptions

Geometry - from 1-4 tiers of 9 PSR06 drums with 4 unmoderated (.05%H_2O) PSR18 drums

Fissile Mass/Concentration - with 640 fuel rods ($U(5)O_2$) and 1280 water rods in each PSR18 drum and with 125g Pu-239 centered sphere in each PSR06 drum in the form of PuO_2.

Reflection/Moderation - Damp air around drums - density optimized to 1.0 g/cm3 H2O for 1 tier
.4 g/cm3 H2O for 2 and 3 tiers
.3 g/cm3 H2O for 4 tiers

The moisture in the PSR06 drums is optimized at .05 gm/cm3.

Additional Reflection - Neutronics albedo mirrored in the x and y directions to approach an infinite array in two directions.

Spacing/Interaction - drums touching and tiers touching.

Enrichment - PSR06 55gal drums - 100% enriched Pu-239,
PSR18 30gal drums - 5 weight % U-235

Model Description

The model evaluated 9 PSR06 drums in close-packed array with 4 unmoderated PSR18 drums. Each PSR06 drum contains the PSR-6 limit as shown in the figure below. The configuration is assumed to be infinite in the x and y directions. The drums are stacked four tiers high.

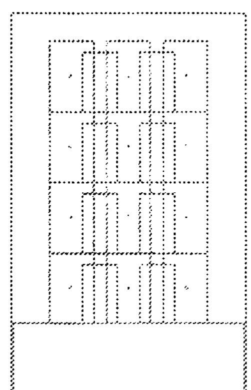
URS

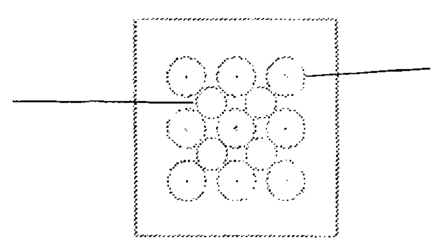
Sheet No. 6/
Calc. No. BUF-04-028
Rev. No. 0

South

1 tier	STH1000	k_{eff}	Sigma	k+2Sigma
Commingling of 9 PSR06 and 4 PSR18 Drums		0.4181	.0026	0.4233
2 tier	STH2000			
Commingling of 18 PSR06 and 8 PSR18 Drums		0.4779	.0019	0.4817
3 tier	STH3000			
Commingling of 27 PSR06 and 12 PSR18 Drums		0.5006	.0014	0.5034
4 tier	STH4000			
Commingling of 36 PSR06 and 16 PSR18 Drums		0.5188	.0010	0.5208

sth4000.wpd





Surround by water. Worst Case 1 tier (Water density = 1.0)
2&3 tier (Water density = 0.4) 4 tier (Water density = 0.3)

URS

Group 028. PSR06 55gal drums predominant intermingled with PSR18 30gal drums. Referred to as SOUTH* cases.

Subgroup 028D - Case STHODD10, ...* 9 PSR06 drums, four PSR18 unmoderated drums, and two PSR18 moderated drums

Assumptions

Geometry - from 1-4 tiers of 9 PSR06 drums, four PSR18 unmoderated drums, and two PSR18 moderated drums

Fissile Mass/Concentration - with 640 fuel rods ($U(5)O_2$) and 1280 water rods in each PSR18 drum and with 125g Pu-239 centered sphere in each PSR06 drum in the form of PuO_2.

Reflection/Moderation - Damp air around drums - density optimized to 1.0 g/cm3 H2O for 1 tier
0.4 g/cm3 H2O for 2 and 3 tiers
0.3 g/cm3 H2O for 4 tiers
The moisture in the moderated PSR18 water rods is optimized to 100% water
The moisture in the PSR06 drums is optimized at .05 gm/cm3.

Additional Reflection - Neutronics albedo mirrored in the x and y directions to approach an infinite array in two directions.

Spacing/Interaction - drums touching and tiers touching.

Enrichment - PSR06 55gal drums - 100% enriched Pu-239,
PSR18 30gal drums - 5 weight % U-235

Model Description

The model evaluated 9 PSR06 drums in close-packed array with 4 unmoderated PSR18 drums. Each PSR06 drum contains the PSR-6 limit as shown in the figure below. Two PSR18 moderated drums are permitted to touch the array. The configuration is assumed to be infinite in the x and y directions. The drums are stacked four tiers high.

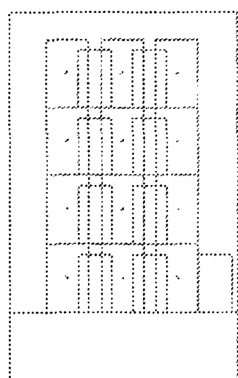
URS

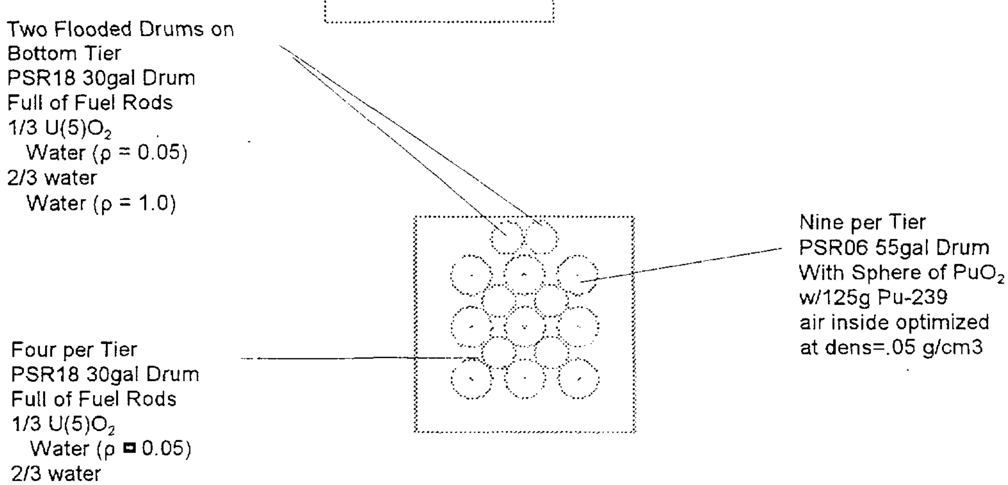
Sheet No. 8/
Calc. No. BUF-04-028
Rev. No. 0

SthOdd40

		k_{eff}	Sigma	k+2Sigma
1 tier	**STHODD10**			
Commingling of 9 PSR06 and 6 PSR18 Drums		**0.8640**	**.0030**	**0.8700**
2 tier	**STHODD20**			
Commingling of 18 PSR06 and 10 PSR18 Drums		**0.8787**	**.0026**	**0.8939**
3 tier	**STHODD30**			
Commingling of 27 PSR06 and 14 PSR18 Drums		**0.8790**	**.0018**	**0.8826**
4 tier	**STHODD40**			
Commingling of 36 PSR06 and 18 PSR18 Drums		**0.8831**	**.0017**	**0.8865**

sthodd40.wpd





Surround by water. Worst Case 1 tier (Water density = 1.0)
2&3 tier (Water density = 0.4) 4 tier (Water density = 0.3)

URS

Sheet No. 9/
Calc. No. BUF-04-028
Rev. No. 0

References and Data Available:

1. Scale 4.4 Manual
2. PSR-6
3. PSR-18
4. NCSE-001
5. NCSE-002
6. Validation Reports in BUF Calc files

Design Criteria: See WVDP-162

Assumptions: See individual Cases and Attachments

Checked by: C Alvin Sweet 3-11-04
Signature Date

Checked by: Russell Dunbar 3/12/04
Signature Date

Approved by: Joseph C. Wolniewicz 05/11/04
Signature Date

URS

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Orchard Park, NY 14127
716 675 7130 Tel
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Calculation Cover Page

Job No: **39399976 / 06354** Calculation No: **BUF-04-029/Rev. 0** Date: **February 27, 2004**

ALTERNATE MIXED DRUMS

Problem Statement & Calculation Objectives: Criticality Calculations were performed to determine if there was a criticality problem when various types of PSR06 and PSR18 containers were commingled.

KENO Inputs and Outputs are on a CD entitled 'NCSE-007'. The worst case is listed in Attachment 2.

Two different groupings or commingling arrays are investigated. OddOdd, and 8BallOdd. Under each group the assumptions, model description, and results are related. Individual container geometries and compositions are covered in Attachment 1.
Assumptions and some description for internal components are covered in Attachment 1 to prevent repetitions.

Group 029. PSR06 55gal drums intermingled with PSR18 30gal drums. Referred to as OddOdd* cases.

Subgroup 029A - Case OddOdd, ...* four PSR06 drums surrounded by12 PSR18 drums plus 2 moderated PSR18 drums

Assumptions

Geometry - from 1-4 tiers of subgroup described above. Only 2 moderated PSR18 drums total each case.

Fissile Mass/Concentration - with 125g Pu-239 centered sphere in each PSR06 drum in the form of PuO_2. PSR18 drums with 640 fuel rods ($U(5)O_2$) and 1280 water rods (.05 water) in each

Reflection/Moderation - Damp air around drums - density optimized to .3 g/cm^3 H2O for all tiers.

The moisture in the moderated PSR18 water rods is optimized at 100% water.
The moisture in the PSR06 drums is optimized at .05 g/cm3.

Additional Reflection - Neutronics albedo mirrored in the x and y directions to approach infinite array.

Spacing/Interaction - drums touching and tiers touching.

Enrichment - PSR06 55gal drums - 100% enriched Pu-239,
PSR18 30gal drums - 5 weight % U-235

Model Description

The model evaluated 4 PSR06 drums in close-packed array with each drum containing the PSR-6 limit as shown in the figure below. These are surrounded by 12 PSR18 drums. The configuration is assumed to be infinite in the x and y dimensions. The drums are stacked four tiers high except for the moderated PSR18 drums which are one tier.

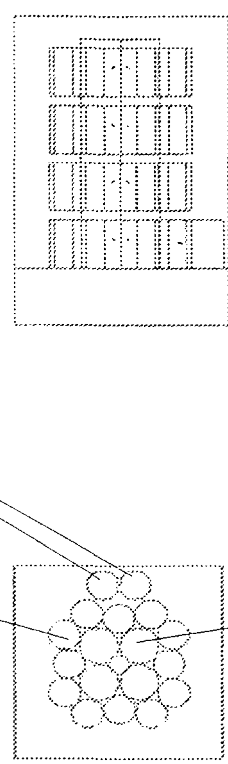
URS

Sheet No. 2/
Calc. No. BUF-04-029
Rev. No. 0

ODDODD4

1 tier	ODDODD1	k_{eff}	Sigma	k+2Sigma
Commingling of 4 PSR06 and 12 PSR18 Drums plus 2 moderated PSR18 Drums		0.9091	.0028	0.9147
2 tiers	ODDODD2			
Commingling of 8 PSR06 and 24 PSR18 Drums plus 2 moderated PSR18 Drums		0.9077	.0022	0.9121
3 tiers	ODDODD3			
Commingling of 12 PSR06 and 36 PSR18 Drums plus 2 moderated PSR18 Drums		0.9096	.0016	0.9128
4 tiers	ODDODD4			
Commingling of 16 PSR06 and 48 PSR18 Drums plus 2 moderated PSR18 Drums		0.9087	.0014	0.9115

oddODD4.wpd



URS

Group 029. PSR06 55gal drums intermingled with PSR18 30gal drums. Referred to as 8BallOdd* cases.

Subgroup 029B - **Case 8BallOdd**, ...* four PSR06 drums surrounded by12 PSR18 drums plus 2 moderated PSR18 drums

Assumptions

Geometry - 8BallOdd -2 tiers of subgroup described above. Only 2 moderated PSR18 drums total.
28Ball - Similar to 8BallOdd except repeat the PSR06 drums to 4 tiers and add another PSR18 normal drum tier to the surrounding drums.

Fissile Mass/Concentration - with 125g Pu-239 offset sphere in each PSR06 drum in the form of PuO_2. PSR18 drums with 640 fuel rods (U(5)O2) and 1280 water rods (.05 water) in each

Reflection/Moderation - Damp air around drums - density optimized to .2 g/cm3 H2O for all cases.

The moisture in the moderated PSR18 water rods is 100% water.
The moisture in the PSR06 drums is optimized to .05 g/cm3.

Additional Reflection - Neutronics albedo mirrored in the x and y directions to approach infinite array.

Spacing/Interaction - drums touching and tiers touching.

Enrichment - PSR06 55gal drums - 100% enriched Pu-239,
PSR18 30gal drums - 5 weight % U-235

Model Description

The first model evaluated 4 PSR06 drums in close-packed array with each drum containing the PSR-6 limit as shown in the figure below. These are surrounded by 12 unmoderated PSR18 drums and 2 moderated PSR18 drums. The configuration is assumed to be infinite in the x and y dimensions. The drums are stacked two tiers high except for the moderated PSR18 drums. The big difference in this case is the offset spheres in the PSR06 drums. The eight spheres are placed as close together as possible in adjacent drums, i.e., spheres above in bottom of drum and spheres below in top of drum

The second model doubles the PSR06 stacking vertically and adds one more layer of PSR18 drums.

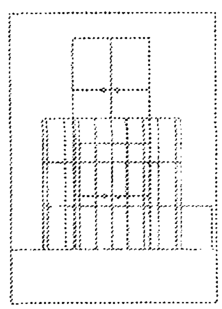
URS

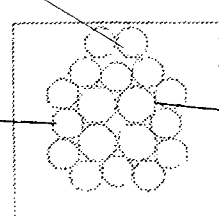
Sheet No. 4/
Calc. No. BUF-04-029
Rev. No. 0

8BALLODD

		k_{eff}	Sigma	k+2Sig
2 tiers PSR06/2tiers PSR18	8BALLODD	0.9163	.0010	0.9183
Commingling of 8 Odd PSR06 and 24 PSR18 Drums PLUS two moderated PSR18 Drums				
4 tiers PSR06/3tiers PSR18	28BALL	0.9172	.0009	0.9190
Commingling of 16 Odd PSR06 and 36 PSR18 Drums PLUS two moderated PSR18 Drums				

8BALLODD.wpd and 28Ball.wpd





URS

Sheet No. 5/
Calc. No. BUF-04-029
Rev. No. 0

References and Data Available:

1. Scale 4.4 Manual
2. PSR-6
3. PSR-18
4. NCSE-001
5. NCSE-002
6. Validation Reports in BUF Calc files

Design Criteria: See WVDP-162

Assumptions: See individual Cases and Attachments

Prepared by:	C Alvin Sweet Signature	3-12-04 Date
Checked by:	Russell Dunham Signature	3/16/04 Date
Approved by:	Joseph C. Wolniewicz Signature	05/11/04 Date

URS

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Calculation Cover Page

Job No: **39399976 / 06354** Calculation No: **BUF-04-030/Rev. 0** Date: **February 27, 2004**

DRUM/BOX ARRAYS

Problem Statement & Calculation Objectives: Criticality Calculations were performed to detemine if there was a criticality problem when various types of PSR06 and PSR18 containers were commingled.

KENO Inputs and Outputs are on a CD entitled 'NCSE-007'. The worst case is listed in Attachment 2.

Four different groupings or commingling arrays are investigated. B25, B25Odd, B25Slab, and Box. Under each group the assumptions, model description, and results are related. Individual container geometries and compositions are covered in Attachment 1.
Assumptions and some description for internal components are covered in Attachment 1 to prevent repetitions.

Group 030. B25 Box surrounded by drums. Referred to as B25Odd* cases.

Subgroup 030A - Case B25ODD, ...* all PSR18 drums, B25 w/200g Pu-239 sphere centered

Assumptions

Geometry - 1 tier of B25 Box surrounded by 12 normal PSR18 drums plus two moderated PSR18 drums

Fissile Mass/Concentration - with 640 fuel rods ($U(5)O_2$) and 1280 water rods in each PSR18 drum..

Reflection/Moderation - Damp air around drums - density optimized to 1.0 g/cm3 H2O for 1 tier.
The moisture content of the water rods in the two moderated PSR18 drums is optimized at 100% water.
The moisture in the PSR06 drums is optimized at .05 g/cm3.

Additional Reflection - Neutronics albedo mirrored in the x and y directions to approach an infinite array.

Spacing/Interaction - drums touching.

Enrichment - PSR06 B25 Box - 100% enriched Pu-239,
PSR18 30gal drums - 5 weight % U-235

Model Description

The model evaluated 12 PSR18 drums close-packed around a B-25 Box with each drum containing the worst credible configuration as shown in the figure below. The configuration is assumed to be infinite in the x and y dimensions. The drums are not stacked. Two moderated PSR18 drums (640 fuel rods containing U(5)O2 and 1280 water rods containing 100% water) are placed touching the array.

A variation of a thick wall B-25 box substituted for the thin wall B-25 box is investigated as a separate run.

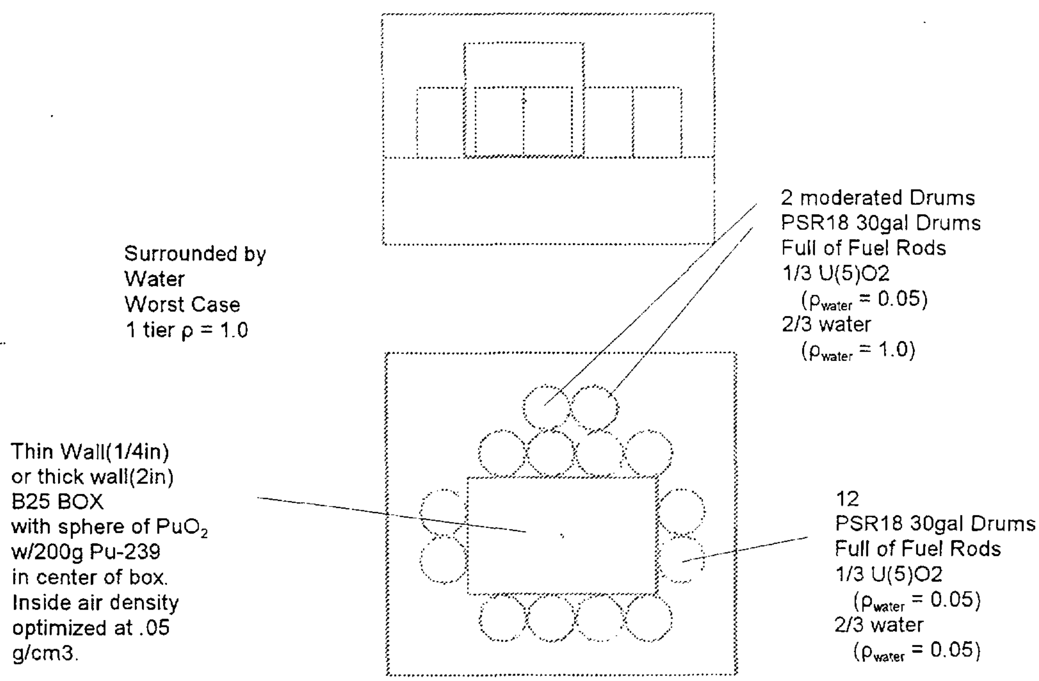
URS

Sheet No. 2/
Calc. No. BUF-04-030
Rev. No. 0

B25ODD

		k_{eff}	Sigma	k+2Sigma
1 tier	**B25ODD**			
Commingling of 12 normal PSR18 Drums and thin wall (1/4in) B25 Box and 2 moderated PSR18 drums		**0.8692**	**.0013**	**0.8718**
1 tier	**B25XODD**			
Commingling of 12 normal PSR18 Drums and thick wall (2in) B25 Box and 2 moderated PSR18 drums		**0.8723**	**.0015**	**0.8753**

B25ODD.WPD



URS

Group 030. PSR06 55gal drums predominant. Referred to as B25P6* cases.

An run identical to B25ODD was made replacing the 12 unmoderated PSR18 drums with PSR06 drums.

Subgroup 030B - Case B25P6ODD, ...* B25, all PSR06 drums, two PSR18 moderated drums

Assumptions

Geometry - 1 tier of B25 Box surrounded by 12 PSR06 drums plus two moderated PSR18 drums

Fissile Mass/Concentration - with 640 fuel rods ($U(5)O_2$) and 1280 water rods in each PSR18 drum, with 125g Pu-239 in each PSR06 drum, and with 200g Pu-239 in B25 Box.

Reflection/Moderation - Damp air around drums - density optimized to 1.0 g/cm3 H2O for 1 tier. The moisture content of the water rods in the two moderated PSR18 drums is 100% water. The moisture in the PSR06 drums and B-25 box optimized at .05 gm/cm3.

Additional Reflection - Neutronics albedo mirrored in the x and y directions to approach an infinite array.

Spacing/Interaction - drums touching.

Enrichment - PSR06 B-25 Box or 55gal drum - 100% enriched Pu-239.
PSR18 30gal drums - 5 weight percent U-235.

Model Description

This run is identical to B25ODD, but replace the 12 unmoderated PSR18 drums with PSR06 drums.

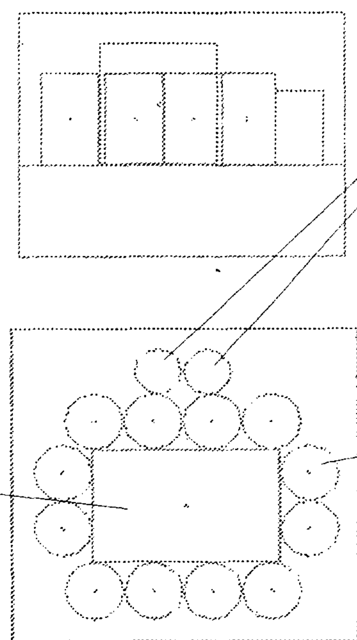
The model evaluated 12 PSR06 drums close-packed around a B-25 Box with each drum containing the PSR-6 limit configuration as shown in the figure below. The configuration is assumed to be infinite in the x and y dimensions. The drums are not stacked. Two moderated PSR18 drums (640 fuel rods containing U(5)O2 and 1280 water rods containing 100% water) are placed touching the array.

URS

B25P6ODD

	k_{eff}	Sigma	k+2Sigma
1 tier B25P6			
Commingling of 12 PSR06 Drums and B25 Box	**0.2759**	**.0012**	**0.2783**
1 tier B25P6ODD			
Commingling of 12 PSR06 Drums and B25 Box and 2 moderated PSR18 drums	**0.8367**	**.0018**	**0.8403**

B25P6ODD.WPD



URS

Group 030. Two arrays of B25 Box surrounded by drums. Referred to as B25Slab* cases.

Subgroup 030C - Case B25SLAB, ...* all PSR18 drums, and B-25 box w/200g Pu-239 slab centered in B25 Box.

Assumptions

Geometry - two moderated PSR18 drums sandwiched between two arrays of B25 Box surrounded by 12 PSR18 drums. 200g Pu-239 slab of PuO2 (100cm x100cm x .002094cm) in B25 Box.

Fissile Mass/Concentration - with 640 fuel rods (U(5)O_2) and 1280 water rods(5% water) in each normal PSR18 drum. The moderated PSR18 drums are the same except the water rods are 100% water.

Reflection/Moderation - Damp air around drums - density optimized to .3 g/cm3 H2O for 1-4 tiers
The moisture content of the water rods in the two moderated PSR18 drums is 100% water.
The moisture in the B-25 box optimized at .05 g/cm3.

Additional Reflection - Neutronics albedo mirrored in the x and y directions to approach an infinite array.

Spacing/Interaction - drums touching box.

Enrichment - PSR06 B-25 Box - 100% enriched Pu-239.
PSR18 drums - 5 weight percent U-235.

Model Description

The model evaluated two moderated PSR18 drums sandwiched between two arrays of B25 Box each surrounded by 12 PSR18 drums. 12 PSR18 drums close-packed around a B-25 Box with each drum containing the worst credible configuration as shown in the figure below. The configuration is assumed to be infinite in the x and y dimensions. There are 1-4 stacked tiers. Two moderated PSR18 drums (640 fuel rods containing U(5)O2 and 1280 water rods containing 100% water) are placed touching the middle of the array.

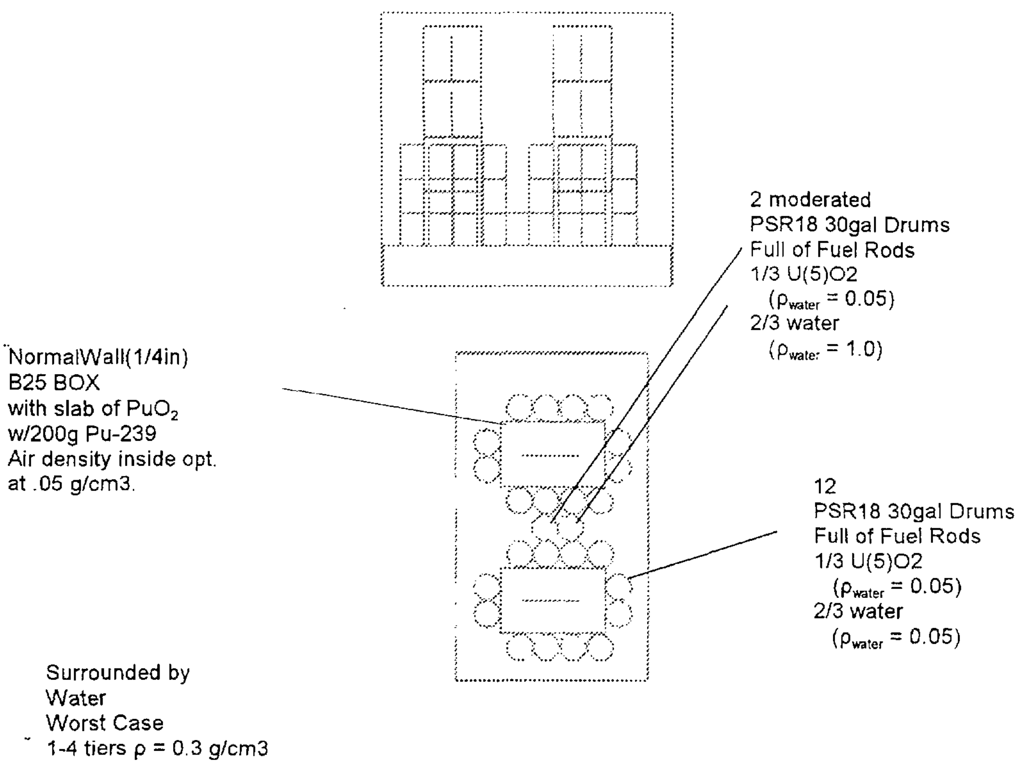
URS

Sheet No. 6/
Calc. No. BUF-04-030
Rev. No. 0

B25SLAB

		k_{eff}	Sigma	k+2Sigma
1 tiers	**B25SLAB6**	**0.8966**	**.0015**	**0.8996**
	2 B25 Boxes and 2 moderated PSR18 Drums and 24 normal PSR18 Drums			
2 tiers	**B25SLAB7**	**0.9068**	**.0012**	**0.9092**
	4 B25 Boxes and 2 moderated PSR18 Drums and 48 normal PSR18 Drums			
3 tiers	**B25SLAB9**	**0.9064**	**.0022**	**0.9108**
	6 B25 Boxes and 2 moderated PSR18 Drums and 72 normal PSR18 Drums			
4 tiers B25	**B25SLAB0**	**0.9058**	**.0027**	**0.9112**
	8 B25 Boxes and 2 moderated PSR18 Drums and 72 normal PSR18 Drums			

B25SLAB0.WPD



URS

Group 030. Four arrays of B25 Box surrounded by drums. Referred to as B25Slab* cases.

Subgroup 030D - Case BOXx, ...* all PSR18 drums, and B-25 box w/200g Pu-239 slab optimally located in B25 Box.

Assumptions

Geometry - two moderated PSR18 drums sandwiched between two arrays of B25 Box surrounded by 12 PSR18 drums. 200g Pu-239 slab of PuO2 (100cm x100cm x .002094cm) in B25 Box.

Fissile Mass/Concentration - with 640 fuel rods (U(5)O_2) and 1280 water rods in each PSR18 drum..

Reflection/Moderation - Damp air around drums - density optimized to .3 g/cm3 H2O for 1-4 tiers
The moisture content of the water rods in the two moderated PSR18 drums is 100% water.
The moisture inside the B-25 Boxes is optimized at .05 g/cm3.

Additional Reflection - Neutronics albedo mirrored in the x and y directions to approach an infinite array.

Spacing/Interaction - drums touching box.

Enrichment - PSR06 B-25 box - 100% enriched Pu-239.
PSR18 drums - 5 weight percent U-235.

Model Description

The model evaluated two moderated PSR18 drums sandwiched between two arrays of B25 Box surrounded by 12 PSR18 drums. 12 PSR18 drums close-packed around a B-25 Box with each drum containing the worst credible configuration as shown in the figure below. The configuration is assumed to be infinite in the x and y dimensions. There are 3 stacked tiers except the center. Each center has two moderated PSR18 drums (640 fuel rods containing U(5)O2 and 1280 water rods containing 100% water) placed touching the middle of the array with two normal PSR18 drums above and two normal PSR18 drums below.

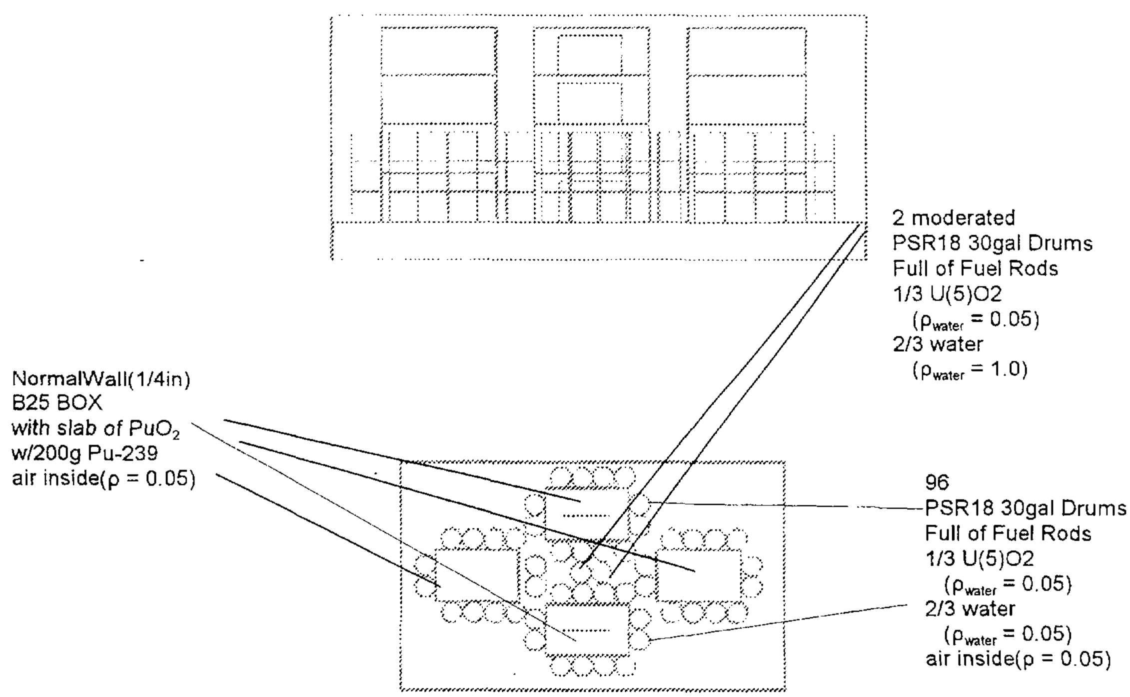
URS

Sheet No. 8/
Calc. No. BUF-04-030
Rev. No. 0

BOX

	k_{eff}	Sigma	k+2Sigma	Case No
2 tiers drums/ 2 tiers B25/ center(2 moder PSR18 between 4 normal PSR18)				
Commingling of 100 PSR18 Drums	0.9201	.0015	0.9231	**BOX9X**
8 B25 Boxes with cuboids tightly packed and 2 moderated PSR18 Drums				
3 tiers drums/ 2 tiers B25/ center(2 moder PSR18 between 4 normal PSR18)				
Commingling of 148 PSR18 Drums	0.9196	.0016	0.9228	**BOX10X**
3 tiers drums/ 3 tiers B25/ center(2 moder PSR18 between 4 normal PSR18)				
Commingling of 148 PSR18 Drums	0.9249	.0007	0.9263	**BOX11BX**
3 tiers drums/ 4 tiers B25/ center(2 moder PSR18 between 4 normal PSR18)				
Commingling of 148 PSR18 Drums	0.9267	.0008	0.9283	**BOX11X**
8-16 B25 Boxes with cuboids tightly packed and 2 moderated PSR18 Drums				

BOX11X.WPD



Surrounded by
Water
Worst Case
2 tier ρ = 0.3

URS

Sheet No. 9/
Calc. No. BUF-04-030
Rev. No. 0

References and Data Available:
1. **Scale 4.4 Manual**
2. **PSR-6**
3. **PSR-18**
4. **NCSE-001**
5. **NCSE-002**
6. **Validation Reports in BUF Calc files**

Design Criteria: See WVDP-162

Assumptions: See individual Cases and Attachments

Prepared by: C Alvin Sweet 3-15-04
Signature Date

Checked by: Russell Dunkan 3/16/04
Signature Date

Approved by: Joseph C. Wolniewicz 05/11/04
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URS

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Calculation Cover Page

Job No: **39399976 / 06354** Calculation No: **BUF-04-031/Rev. 0** Date: **March 1, 2004**

PSR06 MIN BOXES

Problem Statement & Calculation Objectives: Criticality Calculations were performed to determine if there was a criticality problem when various types of PSR06 and PSR18 containers were commingled.

KENO Inputs and Outputs are on a CD entitled 'NCSE-007'. The worst case is listed in Attachment 2.

Two different groupings or commingling arrays are investigated. TN03 and TN05. Under each group the assumptions, model description, and results are related. Individual container geometries and compositions are covered in Attachment 1.
Assumptions and some description for internal components are covered in Attachment 1 to prevent repetitions.

Group 031. PSR06 30inx30inx30in box(minimum 200g PSR06 box) intermingled with PSR18 30gal drums. Referred to as TN* cases.

Subgroup 031A - Case TN03, TN05...* four arrays of PSR06 min boxes each surrounded by 8 PSR18 normal drums.

<u>**Assumptions**</u>

Geometry - 4 tiers of subgroup described above. The PSR18 drums are only 3 high.
TN03 has a central region including 6 normal PSR18 drums stacked 3 tiers of two each.
TN05 is the same as TN03 except it includes 2 moderated PSR18 drums on the ground adjacent to the array.

Fissile Mass/Concentration - with 200g Pu-239 centered sphere in each PSR06 box in the form of PuO_2. PSR18 drums with 640 fuel rods ($U(5)O_2$) and 1280 water rods (.05 water) in each. A special case where the fissile mass is doubled in the PSR06 boxes is evaluated in case TND05. There are 400 g Pu-239 in each box.

Reflection/Moderation - Damp air around drums - density optimized to .3 g/cm^3 H2O for all tiers.

The moisture in the moderated PSR18 water rods is optimized at 100% water.
The moisture in the PSR06 boxes is optimized at .05 g/cm3.

Additional Reflection - Neutronics albedo mirrored in the x and y directions to approach infinite array.

Spacing/Interaction - drums touching and tiers touching. Did not take credit for any pallet spacing.

Enrichment - PSR06 special boxes - 100% enriched Pu-239,
PSR18 30gal drums - 5 weight % U-235

<u>**Model Description**</u>

The model evaluated 16 PSR06 30in x 30in x 30in min boxes in close-packed array with each box containing the PSR-6 limit as shown in the figure below, except in TND05. These are surrounded by 8 PSR18 normal drums each. The configuration is assumed to be infinite in the x and y dimensions. The min boxes are stacked four tiers high, but the PSR18 drums are only 3 tiers high. In the center are 6 PSR18 drums. In the first case adjacent moderated PSR18 drums are missing. In the second case 2 PSR18 moderated drums with 100% water rods are placed touching the array on the ground level.

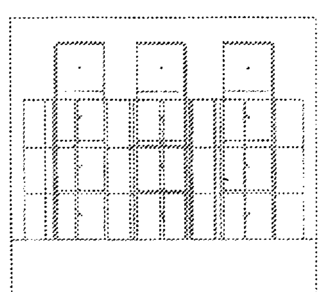
URS

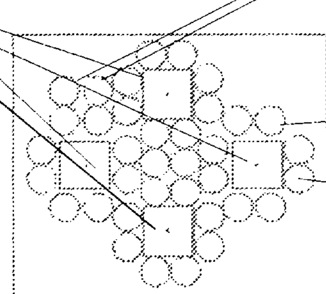
Sheet No. 2/
Calc. No. BUF-04-031
Rev. No. 0

TN

	k_{eff}	Sigma	k+2Sigma	Case No.
Commingling without moder. Drums	**0.8413**	**.0015**	**0.8443**	**TN03**
16 PSR06 Boxes with spheres surrounded by 96 PSR18 normal drums and 6 center(2 normal PSR18 Drums with 2 normal below and 2 normal above)				
Commingling with 2 moder. Drums	**0.8736**	**.0017**	**0.8770**	**TN05**
16 PSR06 Boxes with spheres surrounded by 96 PSR18 normal drums and 6 center(2 normal PSR18 Drums with 2 normal below and 2 normal above) 2 moderated PSR18 drums touching outside of array				
Commingling with 2 moder. Drums	**0.8758**	**.0019**	**0.8796**	**TND05**
Double mass in 16 PSR06 Boxes with spheres surrounded by 96 PSR18 normal drums and 6 center(2 normal PSR18 Drums with 2 normal below and 2 normal above) 2 moderated PSR18 drums touching outside of array				

TN05.WPD





URS

Sheet No. 3/
Calc. No. BUF-04-031
Rev. No. 0

References and Data Available:

1. Scale 4.4 Manual
2. PSR-6
3. PSR-18
4. NCSE-001
5. NCSE-002
6. Validation Reports in BUF Calc files

Design Criteria: See WVDP-162

Assumptions: See individual Cases and Attachments

Prepared by:	C Alvin Sweet **Signature**	3-16-04 **Date**
Checked by:	Russell Dunham **Signature**	3/17/04 **Date**
Approved by:	Joseph C. Wolniewicz **Signature**	05/11/04 **Date**

URS

Calculation Cover Page

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Job No: **39399976.06354** Calculation No: **BUF-04-044/Rev. 0** Date: **March 26, 2004**

Title:

PSR-18 Bound Drum On-Contact Dose Rates

Objective:

To determine the on-contact surface dose rate of a simple 30 gallon steel drum with the contents of a PSR-18 bound container as described in calculations BUF-04-027 through BUF-04-031. Also, to estimate dose rates with varying amounts of shielding.

References and Data Available:

Specific U-235 loading data from calculation BUF-04-031
ORIGEN data (for proportioning other isotopes) based on WVDP-EIS-014, Rev 0.

Assumptions:

- The drums are loaded with 5% enriched U-235 based on specific data from BUF-04-031.
- The drums are simple steel, with no shielding.
- The contents are modeled in MicroShield v. 6.02 as cylindrical sources.
- Buildup is calculated using the transition space as the buildup medium.
- On contact is defined as 1 cm from the surface of the drum at mid height.
- The average density of the contents is assumed to be 10.462 g/cc based on data from BUF-04-0031.
- All isotopes are assumed to be held in proportion to ORIGEN data, which has been adjusted to current and future years.
- Fissionable sources include U-233, U-235, Pu-239, Pu-241.
- Gamma sources are conservatively constrained to Co-60 and Cs-137 only.
- In parametric shielding evaluation, steel shielding thickness and distance to the source are varied and the geometry is changed. In this examination, the equivalent amount of waste in a PSR-18 bound container is placed in a 44.75 x 72 x 46 inch box.

URS

Sheet No. /4
Calc. No. BUF-04-044
Rev. No. 0

Job No: 39399976.06354 Client: WVNS By: Chal Creese Date: 3/26/04
Subject: PSR-18 Bound Drum On-Contact Dose Rates Chk'd.: Al Sweet Date: 3/26/04

Analysis:

Based on calculation BUF-04-031, there are 2.34 x 10^7 g of UO_2 divided equally in 104 drums. 4.39 percent is considered to be U-235, which is 1.02 x 10^6 g or, using a specific activity of 2.16 x 10^{-6} Ci/g, 2.13 x 10^{-2} Ci per drum. The ORIGEN data is corrected from its 1993 level to current with a simple $e^{-\lambda t}$ factor.

ORIGEN data indicates there is a total of 18.3 Ci of U-235 activity. Ratio-ing the ORIGEN to drum activity results in a multiple of 857. Multiplication of the ORIGEN data by the inverse of this factor yields the Ci content per drum of various isotopes.

DRUM
total mass 2.34E+07 g 104 drums

	%	**mass g**	**mass/drum (g)**		**drum activity**	
U-235	4.39E-02	1.02E+06	9.86E+03		2.13E-02	Ci

ORIGEN	**Ci**	**Ci per drum**
U233	1.88E+03	2.20E+00
U235	1.83E+01	2.13E-02
Pu239	8.47E+04	9.87E+01
Pu241	1.82E+06	2.12E+03
Cs137	5.38E+06	6.28E+03
Co60	1.71E+04	1.99E+01

8.57E+02 Ci in ORIGEN/ Ci per drum

Multiple dates for determining ORIGEN activity are calculated, resulting in several sets of results.

Activity in Ci

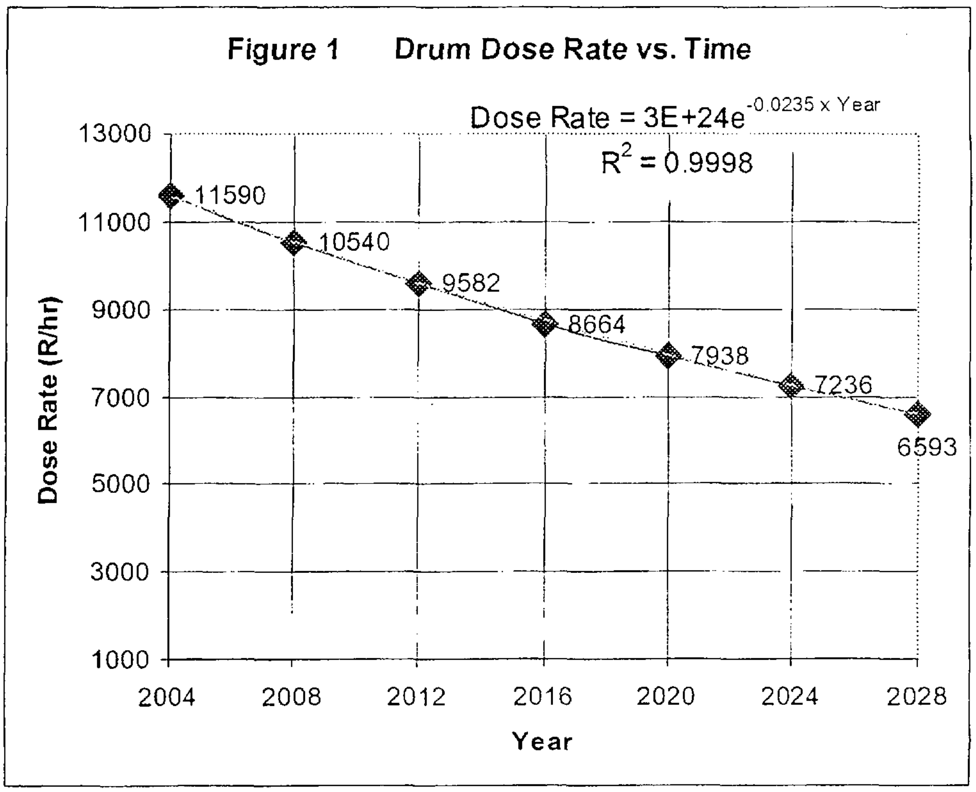
isotope	Year 2004	2008	2012	2016	2020	2024	2028
U233	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00	2.20E+00
U235	2.13E-02	2.13E-02	2.13E-02	2.13E-02	2.13E-02	2.13E-02	2.13E-02
Pu239	9.87E+01	9.87E+01	9.87E+01	9.87E+01	9.87E+01	9.87E+01	9.87E+01
Pu241	2.12E+03	1.75E+03	1.44E+03	1.19E+03	9.77E+02	8.05E+02	6.63E+02
Cs137	6.28E+03	5.72E+03	5.22E+03	4.76E+03	4.34E+03	3.96E+03	3.61E+03
Co60	1.99E+01	1.18E+01	6.95E+00	4.11E+00	2.43E+00	1.43E+00	8.47E-01

The results are entered into MicroShield v 6.02 as the source term. On contact dose estimates are determined for several dates. Results are presented graphically in Figure 1.

URS

Sheet No. /4
Calc. No. BUF-04-044
Rev. No. 0

Job No: 39399976.06354 Client: WVNS By: Chal Creese Date: 3/26/04
Subject: PSR-18 Bound Drum On-Contact Dose Rates Chk'd.: Al Sweet Date: 3/26/04



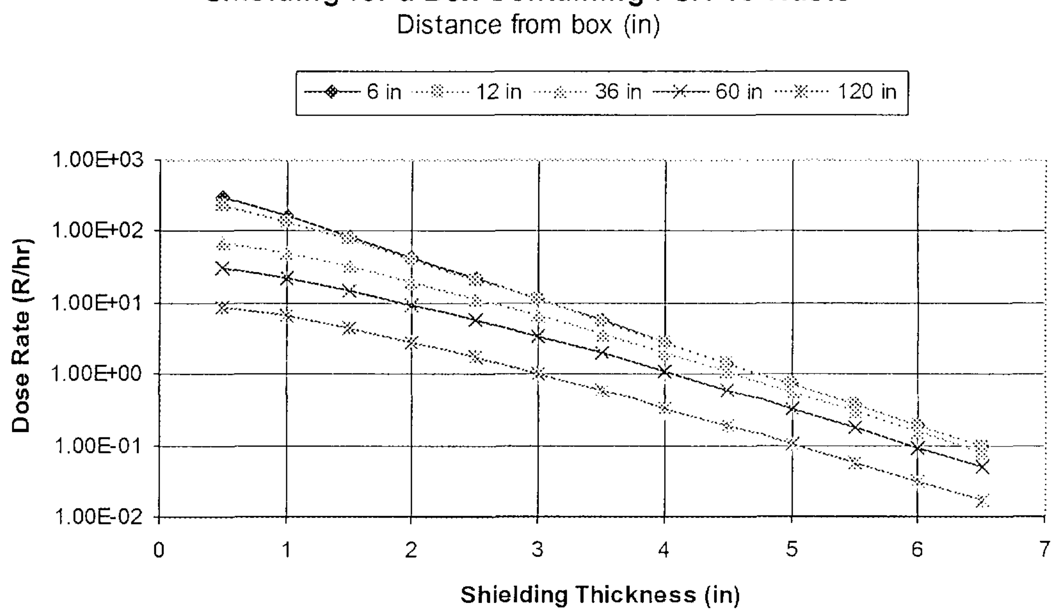
In the subsequent portion of the analysis, for 2004 estimated radionuclide content, the waste in a PSR-18 bound drum is transferred into a box (44.75 x 72 x 46 in). The average density is reduced to keep mass constant. In MicroShield trials, the distance to the box was varied from 6 inches to 10 feet and the shielding thickness ranged from 0 to 6.5 inches (in addition to a modest 0.1 inch minimum box thickness). Proportions of radionuclides are based on ORIGEN proportions. Should HEC CE/PA Composite ratios be used, the Cs-137/U-235 ratio is significantly different - it is 12.35 times greater than the ratio in ORIGEN data. The fissile material is a very small contributor to dose compared to Cs. This means the dose rates based on HEC CE/PA Composite data would be expected to be approximately an order of magnitude higher. To be conservative and account for other fissile materials which may be present and reduce the amount of U-235 (and therefore the Cs-137 amount), the estimated dose may be adjusted from an order of magnitude to a factor of 5.

URS

Sheet No. /4
Calc. No. BUF-04-044
Rev. No. 0

Job No:	39399976.06354	Client: WVNS	By:	Chal Creese	Date: 3/26/04
Subject:	PSR-18 Bound Drum On-Contact Dose Rates		Chk'd.:	Al Sweet	Date: 3/26/04

Figure 2 Dose Rate as a Function of Distance and Shielding for a Box Containing PSR-18 Waste



Conclusions:

Should a steel drum have dose rates less than those indicated above for the appropriate year, it is likely that the contents contain less fissile material than a PSR-18 bound drum used in several analyses. Similarly, should a box have dose rates less than those in Figure 2 for the appropriate shielding and distance, it is unlikely the container would hold greater than a PSR-18 bound drum.

Prepared by:

Signature — Date 3/26/04

Checked By:

C Alvin Sweet — 3/26/04
Signature — Date

Approved by:

Joseph C. Wolniewicz — 05/12/04
Signature — Date

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Calculation Cover Page

Job No: **39399976 / 06354** Calculation No: **BUF-04-032/Rev. 0** Date: **March 1, 2004**

VALIDATION OF THE SCALE-PC (VERSION 4.4a) COMPUTER CODE PACKAGE FOR PLUTONIUM SYSTEMS ENRICHED IN THE Pu-239 ISOTOPE

Problem Statement and Calculation Objectives: This calculation covers the validation of the SCALE pc (Version 4.4a) computer code package for Plutonium systems enriched in the Pu-239 isotope at West Valley Demonstration Plant.

(IBM P4-3060 Personal Computer - Serial No. 412-56-6368-1A)

TABLE OF CONTENTS

1.0 INTRODUCTION

The SCALE-PC (Version 4.4a) computer code package was validated for use on the URS Personal Computer (Serial No. 412-56-6368-1A). These validation calculations were performed for intermediate to high-enriched plutonium systems using the 27-group cross section library. It should be noted that only plutonium systems enriched in the Pu-239 isotope were considered. The systems modeled contained Pu-metal or Plutonium Nitrate solution. The various systems were also modeled using different materials, geometries, arrays, and reflectors.

The plutonium systems analyzed for this report range in enrichments from 71.92 to 99.46 weight percent Pu-239. Therefore, this report develops limits for systems containing plutonium enriched up to 100% in the Pu-239 isotope.

When performing the validation, the American National Standards Institute guidance in ANSI/ANS-8.1[1] was considered. The standard requires that calculational methods used for criticality safety analyses are validated and that any bias be determined by correlating the results of critical experiments with calculations. The methods were the same as those used in the validation performed at Oak Ridge[2].

2.0 DESCRIPTION OF THE SCALE-4.4 SYSTEM

SCALE-4.4 is a modular code system for performing Standardized Computer Analyses for Licensing Evaluations. This system consists of modules to prepare cross-section sets and modules to perform both Monte-Carlo and discrete ordinates neutronics calculations using these cross-section sets. The calculations performed in this validation involved the use of the Monte-Carlo code KENO-Va, developed at the Oak Ridge National Laboratory (ORNL)[3]

A set of Criticality Safety Analysis Sequence (CSAS) control modules is used in the SCALE-4.4 system to call the various functional modules. Because this validation was performed for Monte-Carlo calculations, only the control and functional modules that pertain to the Monte-Carlo calculations are described in this section. For a complete description of the SCALE-4.4 and KENO-Va and KENO-VI system and mathematical methods used therein, refer to the SCALE-4.4 Manual[4].

SCALE.EXE is a frozen version of a system of nuclear criticality safety codes available in the SCALE-4.4 PC package (RSIC #C00545/MNYCP00). The sequence being validated is the CSAS25 sequence documented in the SCALE-4.4 manual. This sequence uses control module CSAS.EXE and program modules 000008.EXE (BONAMI-2), 000002.EXE (NITAWL), and 000009.EXE (KENO-Va). The 27-group ENDF/B-IV cross-section master library, stored in data set FT82F001, was used for all calculations.

2.1 CSAS25 and CSAS4

The CSAS25 and CSAS4 control modules call the functional modules in the order BONAMI (Bondarenko AMPX Interpolator), NITAWL (Nordheim Integral Treatment AMPX Working Library), and KENO-Va. The only difference between the CSAS25 module and the CSAS4 module is that the CSAS4 module allows the user to perform dimensional searches for various geometries and array pitches for given k-effective values. Because the same cross sections (prepared by BONAMI and NITAWL) are used for each KENO-Va run, validations performed using the CSAS25 control module will apply to calculations performed using the CSAS4 module.

2.2 BONAMI

The primary purpose of the BONAMI functional module is to select the required cross-sections and to create a smaller master cross-section library to be processed by NITAWL. This module also performs resonance self-shielding calculations for nuclides that have Bondarenko data associated with their cross sections.

2.3 NITAWL

The NITAWL functional module treats the resonance region cross sections for resonance absorbers. This treatment is based upon the Nordheim Integral Transform method. The user has the option of treating the resonance parameters in the manner most appropriate for the problem detail. The three methods used are as follows (with description):

1. **INFHOMMEDIUM** This option treats the material as an infinite homogeneous mixture.
2. **LATTICECELL** This option treats a multiple repeated cell for resonance self-shielding correction.
3. **MULTIREGION** This option treats a single cell for resonance self-shielding correction.

2.4 KENO

The KENO code uses the integral form of the neutron transport equation to solve for an eigenvalue k, which is the multiplication constant or k-effective (k_{eff}). KENO uses a Monte-Carlo technique to determine neutron mean free path, absorption, fission, scattering, and leakage. The k-effective value indicates the degree to which the system being analyzed is subcritical, critical, or supercritical.

The KENO-Va code is a substantial revision of the KENO-IV code. The KENO-Va code allows for holes, array of arrays, enhanced plotting capabilities, and variable chords for hemi-cylinders and hemispheres. The primary purpose of the KENO-Va code is to calculate the k-effective value. However, the code also calculates fissions, fission densities, neutron fluxes, neutron lifetimes, and energy and region dependent absorptions.

The KENO-VI code is a substantial revision of the KENO-Va code. KENO-VI/(CSAS26) would be validated in a separate document.

2.5 27-GROUP CROSS-SECTION LIBRARY FROM ENDF/B-IV

The 27-Group ENDF/B-IV cross section library was created in 1981 from the 218 Group ENDF/B-IV cross section library set. Before that time, the 16 Group Hansen-Roach, Knight-Modified cross section set was most often used. The 27-group set is considered an improvement because more thermal groups are available and because upscatter is included.

2.6 44-GROUP and 238-GROUP CROSS-SECTION LIBRARIES FROM ENDF/B-V

The 123GROUP and 218GROUP cross-section-library keywords were replaced with 44GROUP and 238GROUP. The former libraries, which were the least used of the standard SCALE libraries, were removed as defaults so the new ENDF/B-V libraries, which give more accurate results, could be accessed directly via keyword input.

3.0 DISCUSSION OF RESULTS

A total of 213 (9 metal and 204 Nitrate solution) plutonium NEA benchmark experiments[5] were used to validate the SCALE-4.4 CSAS4 and CSAS25 modules.

Table 1 correlates the new case number with the original directory and case number.

Sheet No. 5/30
Calc. No. BUF-04-032
Rev. No. 0

TABLE 1. NEW CASE NUMBERS

DIRECTORY	CASENO	NEW CASENO
pumf.001	CASE_1	Pmf0101
pumf.002	CASE_1	Pmf0201
pumf.005	CASE_1	Pmf0501
pumf.008	CASE_1	Pmf0801
pumf.009	CASE_1	Pmf0901
pumf.010	CASE_1	Pmf1001
pumf.011	CASE_1	Pmf1101
pumf.018	CASE_1	Pmf18
pumf.033	zppr-21a	Pmf33
PUST.001	CASE_1.T9	PST01001
PUST.001	CASE_2.T9	PST01002
PUST.001	CASE_3.T9	PST01003
PUST.001	CASE_4.T9	PST01004
PUST.001	CASE_5.T9	PST01005
PUST.001	CASE_6.T9	PST01006
PUST.002	CASE_1	PST02001
PUST.002	CASE_2	PST02002
PUST.002	CASE_3	PST02003
PUST.002	CASE_4	PST02004
PUST.002	CASE_5	PST02005
PUST.002	CASE_6	PST02006
PUST.002	CASE_7	PST02007
PUST.003	CASE_1	PST03001
PUST.003	CASE_2	PST03002
PUST.003	CASE_3	PST03003
PUST.003	CASE_4	PST03004
PUST.003	CASE_5	PST03005
PUST.003	CASE_6	PST03006
PUST.003	CASE_7	PST03007
PUST.003	CASE_8	PST03008
PUST.004	CASE_1	PST04001
PUST.004	CASE_2	PST04002
PUST.004	CASE_3	PST04003
PUST.004	CASE_4	PST04004
PUST.004	CASE_5	PST04005
PUST.004	CASE_6	PST04006
PUST.004	CASE_7	PST04007
PUST.004	CASE_8	PST04008
PUST.004	CASE_9	PST04009
PUST.004	CASE_10	PST04010
PUST.004	CASE_11	PST04011
PUST.004	CASE_12	PST04012
PUST.004	CASE_13	PST04013
PUST.005	CASE_1	PST05001
PUST.005	CASE_2	PST05002
PUST.005	CASE_3	PST05003
PUST.005	CASE_4	PST05004
PUST.005	CASE_5	PST05005
PUST.005	CASE_6	PST05006
PUST.005	CASE_7	PST05007
PUST.005	CASE_8	PST05008
PUST.005	CASE_9	PST05009
PUST.006	CASE_1	PST06001

TABLE 1. NEW CASE NUMBERS
(continued)

PUST.006	CASE_2	PST06002
PUST.006	CASE_3	PST06003
PUST.007	CASE_2	PST07002
PUST.007	CASE_3	PST07003
PUST.007	CASE_5	PST07005
PUST.007	CASE_6	PST07006
PUST.007	CASE_7	PST07007
PUST.007	CASE_8	PST07008
PUST.007	CASE_9	PST07009
PUST.007	CASE_10	PST07010
PUST.009	CASE_1	PST09001
PUST.009	CASE_2	PST09002
PUST.009	CASE_3	PST09003
PUST.010	CASE_1.11	PST10001
PUST.010	CASE_1.12	PST10002
PUST.010	CASE_1.9	PST10003
PUST.010	CASE_2.11	PST10004
PUST.010	CASE_2.12	PST10005
PUST.010	CASE_2.9	PST10006
PUST.010	CASE_3.11	PST10007
PUST.010	CASE_3.12	PST10008
PUST.010	CASE_3.9	PST10009
PUST.010	CASE_4.11	PST10010
PUST.010	CASE_4.12	PST10011
PUST.010	CASE_5.11	PST10012
PUST.010	CASE_6.11	PST10013
PUST.010	CASE_7.11	PST10014
PUST.011	CASE_1.16	PST11001
PUST.011	CASE_1.18	PST11002
PUST.011	CASE_2.16	PST11003
PUST.011	CASE_2.18	PST11004
PUST.011	CASE_3.16	PST11005
PUST.011	CASE_3.18	PST11006
PUST.011	CASE_4.16	PST11007
PUST.011	CASE_4.18	PST11008
PUST.011	CASE_5.16	PST11009
PUST.011	CASE_5.18	PST11010
PUST.011	CASE_6.18	PST11011
PUST.011	CASE_7.18	PST11012
PUST.014	CASE_1	PST14001
PUST.014	CASE_2	PST14002
PUST.014	CASE_3	PST14003
PUST.014	CASE_4	PST14004
PUST.014	CASE_5	PST14005
PUST.014	CASE_6	PST14006
PUST.014	CASE_7	PST14007
PUST.014	CASE_8	PST14008
PUST.014	CASE_9	PST14009
PUST.014	CASE_10	PST14010
PUST.014	CASE_11	PST14011
PUST.014	CASE_12	PST14012
PUST.014	CASE_13	PST14013
PUST.014	CASE_14	PST14014
PUST.014	CASE_15	PST14015

TABLE 1. NEW CASE NUMBERS (continued)

PUST.014	CASE_16	PST14016
PUST.014	CASE_17	PST14017
PUST.014	CASE_18	PST14018
PUST.014	CASE_19	PST14019
PUST.014	CASE_20	PST14020
PUST.014	CASE_21	PST14021
PUST.014	CASE_22	PST14022
PUST.014	CASE_23	PST14023
PUST.014	CASE_24	PST14024
PUST.014	CASE_25	PST14025
PUST.014	CASE_26	PST14026
PUST.014	CASE_27	PST14027
PUST.014	CASE_28	PST14028
PUST.014	CASE_29	PST14029
PUST.014	CASE_30	PST14030
PUST.014	CASE_31	PST14031
PUST.014	CASE_32	PST14032
PUST.014	CASE_33	PST14033
PUST.014	CASE_34	PST14034
PUST.015	CASE_1	PST15001
PUST.015	CASE_2	PST15002
PUST.015	CASE_3	PST15003
PUST.015	CASE_4	PST15004
PUST.015	CASE_5	PST15005
PUST.015	CASE_6	PST15006
PUST.015	CASE_7	PST15007
PUST.015	CASE_8	PST15008
PUST.015	CASE_9	PST15009
PUST.015	CASE_10	PST15010
PUST.015	CASE_11	PST15011
PUST.015	CASE_12	PST15012
PUST.015	CASE_13	PST15013
PUST.015	CASE_14	PST15014
PUST.015	CASE_15	PST15015
PUST.015	CASE_16	PST15016
PUST.015	CASE_17	PST15017
PUST.016	CASE_1	PST16001
PUST.016	CASE_2	PST16002
PUST.016	CASE_3	PST16003
PUST.016	CASE_4	PST16004
PUST.016	CASE_5	PST16005
PUST.016	CASE_6	PST16006
PUST.016	CASE_7	PST16007
PUST.016	CASE_8	PST16008
PUST.016	CASE_9	PST16009
PUST.016	CASE_10	PST16010
PUST.016	CASE_11	PST16011
PUST.017	CASE_1	PST17001
PUST.017	CASE_2	PST17002
PUST.017	CASE_3	PST17003
PUST.017	CASE_4	PST17004
PUST.017	CASE_5	PST17005
PUST.017	CASE_6	PST17006
PUST.017	CASE_7	PST17007

TABLE 1. NEW CASE NUMBERS
(continued)

PUST.017	CASE_8	PST17008
PUST.017	CASE_9	PST17009
PUST.017	CASE_10	PST17010
PUST.017	CASE_11	PST17011
PUST.017	CASE_12	PST17012
PUST.017	CASE_13	PST17013
PUST.017	CASE_14	PST17014
PUST.017	CASE_15	PST17015
PUST.017	CASE_16	PST17016
PUST.017	CASE_17	PST17017
PUST.017	CASE_18	PST17018
PUST.020	CASE_1.T8A	PST20001
PUST.020	CASE_2.T8A	PST20002
PUST.020	CASE_3.T8A	PST20003
PUST.020	CASE_5.T8A	PST20005
PUST.020	CASE_6.T8A	PST20006
PUST.020	CASE_7.T8A	PST20007
PUST.020	CASE_8.T8A	PST20008
PUST.020	CASE_9.T8A	PST20009
PUST.020	CASE_10.T8B	PST20010
PUST.020	CASE_11.T8B	PST20011
PUST.020	CASE_12.T8B	PST20012
PUST.020	CASE_13.T8B	PST20013
PUST.020	CASE_14.T8B	PST20014
PUST.020	CASE_15.T8B	PST20015
PUST.021	CASE_7	PST21007
PUST.021	CASE_8	PST21008
PUST.021	CASE_9	PST21009
PUST.021	CASE_10	PST21010
PUST.024	CASE_1	PST24001
PUST.024	CASE_2	PST24002
PUST.024	CASE_3	PST24003
PUST.024	CASE_4	PST24004
PUST.024	CASE_5	PST24005
PUST.024	CASE_6	PST24006
PUST.024	CASE_7	PST24007
PUST.024	CASE_8	PST24008
PUST.024	CASE_9	PST24009
PUST.024	CASE_10	PST24010
PUST.024	CASE_11	PST24011
PUST.024	CASE_12	PST24012
PUST.024	CASE_13	PST24013
PUST.024	CASE_14	PST24014
PUST.024	CASE_15	PST24015
PUST.024	CASE_16	PST24016
PUST.024	CASE_17	PST24017
PUST.024	CASE_18	PST24018
PUST.024	CASE_19	PST24019
PUST.024	CASE_20	PST24020
PUST.024	CASE_21	PST24021
PUST.024	CASE_22	PST24022
PUST.024	CASE_23	PST24023

The experimental k values for various validation experiments were not unity and therefore the calculated k-effective values should be normalized to the experimental value using the formula $k_{report} = k_{calc}/k_{exp}$, where the subscripts "report," "calc," and "exp" refer to the k values reported, calculated, and experimental, respectively.

The calculations performed for the URS validation were made using 110 to 210 generations with 500 to 2500 neutrons per generation. The k-effective values for the first 5-10 generations were not included in the mean k-effective calculation because the poor spatial distribution of the neutrons would tend to bias the results. The results of the metal calculations are given in Appendix A and the results of the Nitrate solution calculations are given in Appendix B. The data was also determined to be normally distributed.

The statistical analysis procedure consisted of determining a mean and a standard deviation for the set of k-effective values being analyzed. A one-sided lower tolerance limit was then determined such that one can predict with 95% confidence that 99.9% of the k-effective values for critical systems will lie above this limit. One can then be confident that a k-effective below this limit represents a subcritical condition. For this application, the lower tolerance limit was designated the Upper Safety Limit (USL). The statistical method used is explained in Reference 6 and the factors for the one-sided tolerance limits (tolerance limit factors) are given in Reference 7. Refer to Appendix C for more details regarding the USL calculation. Refer to Appendix D for more details regarding the one-sided Tolerance Interval calculation. This technique is similar to the technique proposed by H. R. Dyer[8], except that the data was pooled rather than being used with a correlating parameter (e.g., moderating ratio, average energy group causing fission, or ratio of total fissions to thermal fissions). It was concluded that the validation data did not correlate well with other parameters. The bias is defined as the difference between the average and the true value or, as in the case of this validation, the difference between the arithmetic mean of calculated k-effective values (for various benchmark groupings) and the experimental k-effective value (i.e., k_{calc} minus k_{exp}). It should also be noted that the value of the USL contains the bias (i.e., the bias is included in the expression "$\bar{X}$ - $T_{(n,\gamma,P)}s$").

Statistical analyses were performed for various groupings of validation cases. Refer to the table below for these results:

TABLE OF STATISTICAL ANALYSES						
Grouping	**No. of Cases**	**Mean k-eff**	**Standard Deviation**	**Bias**	**Tolerance Limit Factor[10]**	**USL**
Entire Set	213	1.0139	0.0056	(+)0.0139	3.3830	0.9950
Metal cases	9	0.9979	0.0091	(-)0.0021	5.3624	0.9491
Nitrate cases	204	1.0146	0.0041	(+)0.0146	3.3899	1.0007

$$\text{Bias} = \bar{X} \text{ minus } 1.0$$

$$\text{Upper Safety Limit} \equiv \text{USL} = X_L = \bar{X} - T_{(n,\gamma,P)}s$$

For safety analysis purposes, a calculated k-effective plus two standard deviations must lie below the USL (i.e., $k_{eff} + 2\sigma < \text{USL}$). This statistical method for code validation allows the USL to be established such that there is a high degree of confidence that a calculated result which satisfies the acceptance criteria is indeed subcritical.

Although a margin of subcriticality is not specifically determined by the technique, a margin can be defined as the difference between the one-sided 95% lower confidence limit and the USL (also called the 95/99.9 lower tolerance limit)[7,8]. The one-sided 95% lower confidence limit is defined by the equation

$$\bar{x} - T_p s$$

where T_p is read from a table of the inverse normal probability distribution. The value of T_p varies with the number of samples[9]. Refer to the following table for calculated margins of subcriticality:

TABLE OF STATISTICAL ANALYSES				
Grouping	95% Lower Confidence Limit	Tolerance Limit Factor	USL	Margin of Subcriticality
Entire Set	1.0037	1.8294	0.9950	0.00870
Metal	0.9707	2.9917	0.9491	0.02157
Nitrate	1.0071	1.8337	1.0007	0.00638

95% Lower Confidence Limit ≡ LCL = $\bar{x} - T_{(n,\gamma,P)}s$
Theoretical Margin of Subcriticality = 95% LCL - USL

Since the bias is included in the USL, and since all USLs are greater than 0.9490, the real margin of subcriticality is the difference between the one-sided lower 95% confidence limit and 0.9490. Refer to the following table for the recalculated margins of subcriticality:

MARGINS OF SUBCRITICALITY		
Grouping	95% Lower Confidence Limit	Margin of Subcriticality
Entire Set	1.0037	0.05470
Metal	0.9707	0.02168
Nitrate	1.0071	0.05808

According to generally accepted practice, the margin of subcriticality should be at least 0.02. When recalculated, the margin of subcriticality for all groupings is at least 0.021.

For plutonium-bearing materials other than those modeled in these calculations and for other Pu-239 enrichments, a (-)0.01 Δk uncertainty is applied to the minimum USL calculated for the various subsets. Δk is all other unknown uncertainties. This results in a lower USL of **0.9491 - 0.0101 = 0.939.**

4.0 CONCLUSIONS

The SCALE-PC (Version 4.4) computer code package accurately calculates a broad range of critical experiments and can be used with great confidence for the design and criticality safety analysis of plutonium-bearing systems.

This validation meets the criteria for "validation of a calculational method" specified in Reference 1 (Section 4.3) as follows:

Types of systems that can be modeled:

Systems enriched in the Pu-239 isotope
All chemical forms of plutonium compounds
All physical forms of plutonium compounds
Moderated and unmoderated systems
Single units and arrays
All geometries

Range of parameters which may be treated:

Enrichment: Any (wt.% Pu-239 only)
Moderators: Any
Degrees of Moderation: All
Reflectors: Any
Concentration/Density: Pu Metal at theoretical density to infinitely dilute solutions

Bias in the results produced by this method:

The lowest mean k-effective for any set of cases occurred for the metal plutonium cases, which had a bias of (-)0.0021 (i.e., $k_{calculated}$ minus $k_{experimental}$).

Margin of Subcriticality:

The smallest margin of subcriticality for any set of cases occurred for the metal plutonium cases, which had a margin of subcriticality of 0.0216.

Since the bias is included in the USL, and since the USL for the worst subset is less than 0.95, the maximum allowable calculated k-effective plus two standard deviations for these materials shall be less than or equal to **0.939** (i.e., $k_{eff} + 2\sigma \leq 0.939$).

Note: Although this validation utilized the values of NPG≥300 and GEN≥103 (resulting in tracking 30,000 neutron histories after skipping the first three generations), increasing the number of neutrons and/or the number of generations (for a calculation) does not violate the basis of acceptable subcriticality as documented in this validation report. While tracking more neutron histories will permit better convergence of the calculations, it also tends to lower the standard deviation of the calculation. However, as stated previously, this does not violate the basis of acceptable subcriticality.

5.0 REFERENCES

1) American National Standard, ANSI/ANS-8.1, Section 4.3, American Nuclear Society, 1983.

2) W. C. Jordan, N. F. Landers, L. M. Petrie, Validation of KENO-Va, Comparison With Critical Experiments, ORNL/CSD/TM-238, December 1986.

3) Radiation Shielding Information Center, C00545/MNYCP00, Oak Ridge National Laboratory, March 2000.

4) L. M. Petrie, N. F. Landers, KENO Va: An Improved Monte Carlo Program with Supergrouping, NUREG/CR-0200, Oak Ridge National Laboratory, March 2000.

5) Nuclear Energy Agency, Volumes I through VII, International Handbook of Evaluated Criticality Safety Benchmark Experiments, October 1992.

6) M. G. Natrella, Experimental Statistics, National Bureau of Standards Handbook 91, National Institute of Standards and Technology, August 1963.

7) D. B. Owen, Factors for One-Sided Tolerance Limits and for Variable Sampling Plans, SCR-607, Sandia Corporation Monograph, March 1963.

8) H. R. Dyer, W. C. Jordan, V. R. Cain, "A Technique for Code Validation for Criticality Safety Calculations," Transactions of the American Nuclear Society, 63, 238, (June 1991).

9) D. B. Owen, Handbook of Statistical Tables, Addison-Wesley, Page 12, 1962.

APPENDIX A
Summary of PC SCALE-4.4/KENO-Va
Plutonium Metal Validation Calculations

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enr.	σ^2
PMF0101	0.9963	0.0022	Pu metal w/ copper	Sphere	none	95.00	4.84e-06
PMF0201	0.9983	0.0015	Pu metal w/ copper	Sphere	none	76.40	2.25e-06
PMF0501	1.0008	0.0016	Pu metal w/ copper	Sphere	tungsten	94.79	2.56e-06
PMF0801	0.9773	0.0016	Pu metal w/ copper	Sphere	thorium	94.57	2.56e-06
PMF0901	0.9930	0.0018	Pu metal w/ copper	Sphere	aluminum	94.82	3.24e-06
PMF1001	0.9962	0.0016	Pu metal w/ copper	Sphere	uranium	94.79	2.56e-06
PMF1101	0.9993	0.0016	Pu metal	Sphere	H2O	94.41	2.56e-06
PMF18	1.0086	0.0019	Pu metal w/ copper	Sphere	BeO	94.79	3.61e-06
PMF33	1.0111	0.0003	Metal Rods - Pu + Zr	Sq. Pitch Array	Graphite, etc	94.12	9.00e-06

APPENDIX B
Summary of PC SCALE-4.4/KENO-Va
Plutonium Nitrate Validation Calculations

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
PST01001	1.0131	0.0029	Pu Nitrate soln	Sphere	H2O	94.97	8.410e-06
PST01002	1.0144	0.0031	Pu Nitrate soln	Sphere	H2O	95.16	9.610e-06
PST01003	1.0188	0.0030	Pu Nitrate soln	Sphere	H2O	96.64	9.000e-06
PST01004	1.0172	0.0034	Pu Nitrate soln	Sphere	H2O	95.18	1.156e-05
PST01005	1.0180	0.0029	Pu Nitrate soln	Sphere	H2O	95.17	8.410e-06
PST01006	1.0181	0.0029	Pu Nitrate soln	Sphere	H2O	95.53	8.410e-06
PST02001	1.0194	0.0036	Pu Nitrate soln	Sphere	H2O	96.89	1.296e-05
PST02002	1.0171	0.0029	Pu Nitrate soln	Sphere	H2O	96.91	8.410e-06
PST02003	1.0136	0.0028	Pu Nitrate soln	Sphere	H2O	96.89	7.840e-06
PST02004	1.0163	0.0032	Pu Nitrate soln	Sphere	H2O	96.94	1.024e-05
PST02005	1.0240	0.0027	Pu Nitrate soln	Sphere	H2O	96.88	7.290e-06
PST02006	1.0177	0.0028	Pu Nitrate soln	Sphere	H2O	96.88	7.840e-06
PST02007	1.0189	0.0027	Pu Nitrate soln	Sphere	H2O	96.91	7.290e-06
PST03001	1.0129	0.0028	Pu Nitrate soln	Sphere	H2O	98.20	7.840e-06
PST03002	1.0114	0.0027	Pu Nitrate soln	Sphere	H2O	98.25	7.290e-06
PST03003	1.0166	0.0025	Pu Nitrate soln	Sphere	H2O	96.89	6.250e-06
PST03004	1.0131	0.0025	Pu Nitrate soln	Sphere	H2O	96.90	6.250e-06
PST03005	1.0175	0.0027	Pu Nitrate soln	Sphere	H2O	96.89	7.290e-06
PST03006	1.0136	0.0029	Pu Nitrate soln	Sphere	H2O	96.89	8.410e-06
PST03007	1.0209	0.0030	Pu Nitrate soln	Sphere	H2O	96.90	9.000e-06
PST03008	1.0181	0.0028	Pu Nitrate soln	Sphere	H2O	96.89	7.840e-06
PST04001	1.0188	0.0027	Pu Nitrate soln	Sphere	H2O	99.46	7.290e-06
PST04002	1.0087	0.0029	Pu Nitrate soln	Sphere	H2O	99.46	8.410e-06
PST04003	1.0080	0.0027	Pu Nitrate soln	Sphere	H2O	99.46	7.290e-06
PST04004	1.0160	0.0027	Pu Nitrate soln	Sphere	H2O	99.46	7.290e-06

APPENDIX B
Summary of PC SCALE-4.4/KENO-Va
Plutonium Nitrate Validation Calculations
(continued)

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
PST04005	1.0084	0.0027	Pu Nitrate soln	Sphere	H2O	98.25	7.290e-06
PST04006	1.0146	0.0028	Pu Nitrate soln	Sphere	H2O	96.89	7.840e-06
PST04007	1.0165	0.0029	Pu Nitrate soln	Sphere	H2O	96.90	8.410e-06
PST04008	1.0166	0.0027	Pu Nitrate soln	Sphere	H2O	96.90	7.290e-06
PST04009	1.0095	0.0025	Pu Nitrate soln	Sphere	H2O	96.90	6.250e-06
PST04010	1.0107	0.0024	Pu Nitrate soln	Sphere	H2O	98.89	5.760e-06
PST04011	1.0140	0.0029	Pu Nitrate soln	Sphere	H2O	96.89	8.410e-06
PST04012	1.0095	0.0028	Pu Nitrate soln	Sphere	H2O	96.89	7.840e-06
PST04013	1.0115	0.0027	Pu Nitrate soln	Sphere	H2O	96.58	7.290e-06
PST05001	1.0118	0.0027	Pu Nitrate soln	Sphere	H2O	95.97	7.290e-06
PST05002	1.0172	0.0029	Pu Nitrate soln	Sphere	H2O	95.97	8.410e-06
PST05003	1.0176	0.0028	Pu Nitrate soln	Sphere	H2O	95.97	7.840e-06
PST05004	1.0165	0.0027	Pu Nitrate soln	Sphere	H2O	95.96	7.290e-06
PST05005	1.0179	0.0027	Pu Nitrate soln	Sphere	H2O	95.97	7.290e-06
PST05006	1.0160	0.0030	Pu Nitrate soln	Sphere	H2O	95.97	9.000e-06
PST05007	1.0158	0.0024	Pu Nitrate soln	Sphere	H2O	95.97	5.760e-06
PST05008	1.0116	0.0024	Pu Nitrate soln	Sphere	H2O	95.61	5.760e-06
PST05009	1.0138	0.0026	Pu Nitrate soln	Sphere	H2O	95.61	6.760e-06
PST06001	1.0115	0.0027	Pu Nitrate soln	Sphere	H2O	96.89	7.290e-06
PST06002	1.0138	0.0028	Pu Nitrate soln	Sphere	H2O	96.89	7.840e-06
PST06003	1.0104	0.0027	Pu Nitrate soln	Sphere	H2O	96.89	7.290e-06
PST07002	1.0175	0.0029	Pu Nitrate soln	Sphere	H2O	95.03	8.410e-06
PST07003	1.0175	0.0028	Pu Nitrate soln	Sphere	H2O	95.03	7.840e-06
PST07005	1.0156	0.0033	Pu Nitrate soln	Sphere	H2O	95.05	1.089e-05
PST07006	1.0067	0.0028	Pu Nitrate soln	Sphere	H2O	95.03	7.840e-06

APPENDIX B
Summary of PC SCALE-4.4/KENO-Va
Plutonium Nitrate Validation Calculations
(continued)

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
PST07007	1.0106	0.0030	Pu Nitrate soln	Sphere	H2O	95.04	9.000e-06
PST07008	1.0042	0.0034	Pu Nitrate soln	Sphere	H2O	95.03	1.156e-05
PST07009	1.0022	0.0029	Pu Nitrate soln	Sphere	H2O	95.03	8.410e-06
PST07010	1.0120	0.0034	Pu Nitrate soln	Sphere	H2O	95.04	1.156e-05
PST09001	1.0262	0.0015	Pu Nitrate soln	Sphere	BARE	97.41	2.250e-06
PST09002	1.0292	0.0017	Pu Nitrate soln	Sphere	BARE	97.41	2.890e-06
PST09003	1.0300	0.0015	Pu Nitrate soln	Sphere	BARE	97.39	2.250e-06
PST10001	1.0175	0.0031	Pu Nitrate soln	Cylinder	H2O	97.16	9.610e-06
PST10002	1.0183	0.0028	Pu Nitrate soln	Cylinder	H2O	97.11	7.840e-06
PST10003	1.0231	0.0032	Pu Nitrate soln	Cylinder	H2O	97.16	1.024e-05
PST10004	1.0122	0.0028	Pu Nitrate soln	Cylinder	H2O	97.16	7.840e-06
PST10005	1.0209	0.0023	Pu Nitrate soln	Cylinder	H2O	97.11	5.290e-06
PST10006	1.0180	0.0030	Pu Nitrate soln	Cylinder	H2O	97.15	9.000e-06
PST10007	1.0207	0.0033	Pu Nitrate soln	Cylinder	H2O	97.16	1.089e-05
PST10008	1.0178	0.0026	Pu Nitrate soln	Cylinder	H2O	97.11	6.760e-06
PST10009	1.0187	0.0025	Pu Nitrate soln	Cylinder	H2O	97.16	6.250e-06
PST10010	1.0140	0.0029	Pu Nitrate soln	Cylinder	H2O	97.16	8.410e-06
PST10011	1.0197	0.0028	Pu Nitrate soln	Cylinder	H2O	97.11	7.840e-06
PST10012	1.0103	0.0029	Pu Nitrate soln	Cylinder	H2O	97.16	8.410e-06
PST10013	1.0199	0.0029	Pu Nitrate soln	Cylinder	H2O	97.11	8.410e-06
PST10014	1.0077	0.0030	Pu Nitrate soln	Cylinder	H2O	97.11	9.000e-06
PST11001	1.0173	0.0031	Pu Nitrate soln	Sphere	BARE	95.84	9.610e-06
PST11002	1.0036	0.0027	Pu Nitrate soln	Sphere	BARE	95.82	7.290e-06
PST11003	1.0255	0.0030	Pu Nitrate soln	Sphere	BARE	95.85	9.000e-06
PST11004	1.0092	0.0027	Pu Nitrate soln	Sphere	BARE	95.82	7.290e-06

APPENDIX B
Summary of PC SCALE-4.4/KENO-Va
Plutonium Nitrate Validation Calculations
(continued)

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
PST11005	1.0271	0.0029	Pu Nitrate soln	Sphere	BARE	95.85	8.410e-06
PST11006	1.0076	0.0023	Pu Nitrate soln	Sphere	BARE	95.82	5.290e-06
PST11007	1.0201	0.0030	Pu Nitrate soln	Sphere	BARE	95.85	9.000e-06
PST11008	1.0035	0.0026	Pu Nitrate soln	Sphere	BARE	95.82	6.760e-06
PST11009	1.0144	0.0031	Pu Nitrate soln	Sphere	BARE	95.85	9.610e-06
PST11010	1.0101	0.0024	Pu Nitrate soln	Sphere	BARE	95.82	5.760e-06
PST11011	1.0127	0.0027	Pu Nitrate soln	Sphere	BARE	95.82	7.290e-06
PST11012	1.0146	0.0031	Pu Nitrate soln	Sphere	BARE	95.82	9.610e-06
PST14001	1.0166	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.45	1.210e-06
PST14002	1.0130	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.210e-06
PST14003	1.0145	0.0012	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.440e-06
PST14004	1.0129	0.0012	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.440e-06
PST14005	1.0141	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.210e-06
PST14006	1.0142	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.210e-06
PST14007	1.0128	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.210e-06
PST14008	1.0122	0.0010	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.000e-06
PST14009	1.0105	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.210e-06
PST14010	1.0134	0.0010	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.000e-06
PST14011	1.0129	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.210e-06
PST14012	1.0127	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.210e-06
PST14013	1.0151	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.210e-06
PST14014	1.0127	0.0012	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.440e-06
PST14015	1.0130	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.210e-06
PST14016	1.0129	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.210e-06
PST14017	1.0165	0.0012	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.440e-06

APPENDIX B
Summary of PC SCALE-4.4/KENO-Va
Plutonium Nitrate Validation Calculations
(continued)

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
PST14018	1.0163	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.210e-06
PST14019	1.0122	0.0010	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.000e-06
PST14020	1.0129	0.0013	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.690e-06
PST14021	1.0152	0.0013	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.690e-06
PST14022	1.0138	0.0010	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.000e-06
PST14023	1.0131	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.210e-06
PST14024	1.0158	0.0010	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.000e-06
PST14025	1.0105	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.210e-06
PST14026	1.0128	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.210e-06
PST14027	1.0129	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.210e-06
PST14028	1.0134	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.210e-06
PST14029	1.0119	0.0010	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.000e-06
PST14030	1.0142	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.210e-06
PST14031	1.0107	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.210e-06
PST14032	1.0120	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.210e-06
PST14033	1.0122	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.46	1.210e-06
PST14034	1.0144	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.45	1.210e-06
PST15001	1.0157	0.0010	Pu Nitrate soln	Cylinder	Pyrex	95.45	1.000e-06
PST15002	1.0137	0.0012	Pu Nitrate soln	Cylinder	Pyrex	95.45	1.440e-06
PST15003	1.0128	0.0010	Pu Nitrate soln	Cylinder	Pyrex	95.45	1.000e-06
PST15004	1.0146	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.45	1.210e-06
PST15005	1.0150	0.0010	Pu Nitrate soln	Cylinder	Pyrex	95.45	1.000e-06
PST15006	1.0160	0.0010	Pu Nitrate soln	Cylinder	Pyrex	95.45	1.000e-06
PST15007	1.0163	0.0010	Pu Nitrate soln	Cylinder	Pyrex	95.45	1.000e-06
PST15008	1.0139	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.45	1.210e-06

APPENDIX B
Summary of PC SCALE-4.4/KENO-Va
Plutonium Nitrate Validation Calculations
(continued)

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
PST15009	1.0155	0.0012	Pu Nitrate soln	Cylinder	Pyrex	95.45	1.440e-06
PST15010	1.0149	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.45	1.210e-06
PST15011	1.0124	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.45	1.210e-06
PST15012	1.0139	0.0012	Pu Nitrate soln	Cylinder	Pyrex	95.45	1.440e-06
PST15013	1.0154	0.0012	Pu Nitrate soln	Cylinder	Pyrex	95.45	1.440e-06
PST15014	1.0165	0.0012	Pu Nitrate soln	Cylinder	Pyrex	95.45	1.440e-06
PST15015	1.0160	0.0010	Pu Nitrate soln	Cylinder	Pyrex	95.45	1.000e-06
PST15016	1.0135	0.0009	Pu Nitrate soln	Cylinder	Pyrex	95.45	8.100e-07
PST15017	1.0138	0.0011	Pu Nitrate soln	Cylinder	Pyrex	95.45	1.210e-06
PST16001	1.0147	0.0012	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.440e-06
PST16002	1.0133	0.0012	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.440e-06
PST16003	1.0172	0.0012	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.440e-06
PST16004	1.0172	0.0011	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.210e-06
PST16005	1.0144	0.0012	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.440e-06
PST16006	1.0141	0.0011	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.028e+00
PST16007	1.0128	0.0011	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.210e-06
PST16008	1.0156	0.0011	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.210e-06
PST16009	1.0135	0.0011	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.210e-06
PST16010	1.0149	0.0012	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.440e-06
PST16011	1.0163	0.0010	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.000e-06
PST17001	1.0140	0.0010	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.000e-06
PST17002	1.0144	0.0010	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.000e-06
PST17003	1.0136	0.0011	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.210e-06
PST17004	1.0123	0.0011	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.210e-06
PST17005	1.0145	0.0011	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.210e-06

APPENDIX B
Summary of PC SCALE-4.4/KENO-Va
Plutonium Nitrate Validation Calculations
(continued)

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
PST17006	1.0167	0.0011	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.210e-06
PST17007	1.0127	0.0010	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.000e-06
PST17008	1.0152	0.0011	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.210e-06
PST17009	1.0128	0.0011	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.210e-06
PST17010	1.0151	0.0011	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.210e-06
PST17011	1.0163	0.0011	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.210e-06
PST17012	1.0153	0.0010	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.000e-06
PST17013	1.0136	0.0011	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.210e-06
PST17014	1.0141	0.0012	Pu Nitrate soln	Cylinder	No Pyrex	95.45	1.440e-06
PST17015	1.0152	0.0012	Pu Nitrate soln	Cylinder	No Pyrex	95.46	1.440e-06
PST17016	1.0160	0.0012	Pu Nitrate soln	Cylinder	No Pyrex	95.46	1.440e-06
PST17017	1.0150	0.0012	Pu Nitrate soln	Cylinder	No Pyrex	95.46	1.440e-06
PST17018	1.0132	0.0011	Pu Nitrate soln	Cylinder	No Pyrex	95.46	1.210e-06
PST20001	1.0136	0.0029	Pu Nitrate soln	Sphere	H2O	95.03	8.410e-06
PST20002	1.0196	0.0031	Pu Nitrate soln	Sphere	H2O	95.03	9.610e-06
PST20003	1.0126	0.0026	Pu Nitrate soln	Sphere	H2O	95.03	6.760e-06
PST20005	1.0136	0.0028	Pu Nitrate soln	Sphere	H2O	95.03	7.840e-06
PST20006	1.0175	0.0031	Pu Nitrate soln	Sphere	H2O	95.03	9.610e-06
PST20007	1.0025	0.0026	Pu Nitrate soln	Sphere	H2O	95.03	6.760e-06
PST20008	1.0131	0.0029	Pu Nitrate soln	Sphere	H2O	95.03	8.410e-06
PST20009	1.0050	0.0028	Pu Nitrate soln	Sphere	H2O	95.03	7.840e-06
PST20010	1.0153	0.0030	Pu Nitrate soln	Sphere	H2O	95.03	9.000e-06
PST20011	1.0124	0.0026	Pu Nitrate soln	Sphere	H2O	95.03	6.760e-06
PST20012	1.0140	0.0029	Pu Nitrate soln	Sphere	H2O	95.03	8.410e-06
PST20013	1.0170	0.0026	Pu Nitrate soln	Sphere	H2O	95.03	6.760e-06

APPENDIX B
Summary of PC SCALE-4.4/KENO-Va
Plutonium Nitrate Validation Calculations
(continued)

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
PST20014	1.0050	0.0032	Pu Nitrate soln	Sphere	H2O	95.03	1.024e-05
PST20015	1.0063	0.0030	Pu Nitrate soln	Sphere	H2O	95.03	9.000e-06
PST21007	1.0162	0.0031	Pu Nitrate soln	Sphere	Bare	95.05	9.610e-06
PST21008	1.0124	0.0034	Pu Nitrate soln	Sphere	Bare	95.05	1.156e-05
PST21009	1.0135	0.0031	Pu Nitrate soln	Sphere	Bare	95.05	9.610e-06
PST21010	1.0175	0.0023	Pu Nitrate soln	Sphere	Bare	95.05	5.290e-06
PST24001	1.0172	0.0020	Pu Nitrate soln	Slab Tank	Plexiglass	76.02	4.000e-06
PST24002	1.0143	0.0021	Pu Nitrate soln	Slab Tank	Plexiglass	76.02	4.410e-06
PST24003	1.0122	0.0022	Pu Nitrate soln	Slab Tank	Plexiglass	76.02	4.840e-06
PST24004	1.0153	0.0019	Pu Nitrate soln	Slab Tank	Plexiglass	76.02	3.610e-06
PST24005	1.0127	0.0019	Pu Nitrate soln	Slab Tank	Plexiglass	76.02	3.610e-06
PST24006	1.0136	0.0019	Pu Nitrate soln	Slab Tank	Plexiglass	76.02	3.610e-06
PST24007	1.0154	0.0020	Pu Nitrate soln	Slab Tank	Plexiglass	76.02	4.000e-06
PST24008	1.0188	0.0018	Pu Nitrate soln	Slab Tank	Plexiglass	76.02	3.240e-06
PST24009	1.0200	0.0018	Pu Nitrate soln	Slab Tank	Plexiglass	76.02	3.240e-06
PST24010	1.0192	0.0017	Pu Nitrate soln	Slab Tank	Plexiglass	76.02	2.890e-06
PST24011	1.0191	0.0019	Pu Nitrate soln	Slab Tank	Plexiglass	76.02	3.610e-06
PST24012	1.0208	0.0018	Pu Nitrate soln	Slab Tank	Plexiglass	76.02	3.240e-06
PST24013	1.0168	0.0018	Pu Nitrate soln	Slab Tank	Plexiglass	76.02	3.240e-06
PST24014	1.0158	0.0020	Pu Nitrate soln	Slab Tank	Plexiglass	71.92	4.000e-06
PST24015	1.0156	0.0018	Pu Nitrate soln	Slab Tank	Plexiglass	71.92	3.240e-06
PST24016	1.0150	0.0018	Pu Nitrate soln	Slab Tank	Plexiglass	71.92	3.240e-06
PST24017	1.0132	0.0021	Pu Nitrate soln	Slab Tank	Plexiglass	71.92	4.410e-06
PST24018	1.0111	0.0019	Pu Nitrate soln	Slab Tank	Plexiglass	76.02	3.610e-06
PST24019	1.0099	0.0018	Pu Nitrate soln	Slab Tank	Plexiglass	76.02	3.240e-06

APPENDIX B
Summary of PC SCALE-4.4/KENO-Va
Plutonium Nitrate Validation Calculations
(continued)

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
PST24020	1.0140	0.0022	Pu Nitrate soln	Slab Tank	Plexiglass	76.02	4.840e-06
PST24021	1.0119	0.0024	Pu Nitrate soln	Slab Tank	Plexiglass	76.02	5.760e-06
PST24022	1.0177	0.0020	Pu Nitrate soln	Slab Tank	Plexiglass	76.02	4.000e-06
PST24023	1.0129	0.0021	Pu Nitrate soln	Slab Tank	Plexiglass	76.02	4.410e-06

APPENDIX C
Sample Statistical Analysis

Find a single value above which it is predicted with 95% confidence that 99.9% of the critical values will lie (M. G. Natrella, Reference 6, page 2-14):

$P = 0.999$

$\gamma = 0.95$

$\bar{X} \equiv$ Arithmetic mean of the benchmark cases = 1.0139

$n \equiv$ Sample size = 213

$s \equiv$ Population Standard Deviation = 0.0056

$T \equiv$ Factor for one-sided tolerance limit (Reference 6, Page 50)

Then, for $T(n,\gamma,P)$ the table value is:

$T(\,213,\,0.95,\,0.999\,) = 3.383$

Upper Safety Limit $\equiv$ USL $= X_L = \bar{X} - T_{(n,\gamma,P)}s = 1.0139 - (3.383)(0.0056) = 0.9950$

Bias* $\equiv k_{calculated} - k_{experimental} = 1.0139 - 1.0000 = (+)0.0139$

*Note: The value of "X_L" also contains the bias (i.e., the bias is included in the expression "$\bar{X} - T_{(n,\gamma,P)}s$").

APPENDIX D
Calculation of the One-Sided Tolerance Interval

The purpose in validating a computer for KENO trials is twofold.

1. Guaranteeing by demonstration that P_1 percent of KENO outputs ($k_{eff} + 2\sigma$) will fall between the lower and upper tolerance limits, i.e., since a critical experiment output is supposed to be 1.0, it is indeed 1.0 + some number and - some number. Since we would not normally be concerned with a number above 1.0 (supercritical), we therefore only look at the lower number which is arbitrarily called a one-sided lower tolerance limit or Upper Safety Limit because it now reflects a new definition of being critical. Another way of saying this is that we are not confident in our calculational methods enough to permit a system under investigation to go above that Upper Safety Limit(USL). Since it may be critical in this case, we show that the USL is above 0.95 and fall back on 0.95 as a conservative measure. Furthermore, although it is not part of this calculation, there is sometimes an administrative decision to fall back even further from theoretical 0.95 to some other number (0.93 for West Valley). To determine the theoretical USL we need to know the following:

    a) How many cases will we run? The number and kind must reflect a true picture of all systems which will be investigated during the lifetime of the computer in question. The number (N) should be at least 20 to satisfy statistics. Twenty is not always possible. Two of our N's were 9 and 16, but these played a minor role.

    b) P_1 percent of population measurements will not fall below the USL. This is more or less decided for us. A number generally accepted by industry and regulatory bodies is 99.9% for nuclear criticality calculations.

    c) P_2 percent confidence level that the USL calculated reflects a true number based on accurate assumptions. A number generally accepted by industry and regulatory bodies is 95% for nuclear criticality calculations. There are too many unknowns generally to have a higher number.

2. Demonstrating that the Margin of Subcriticality (MS) is 0.02 or greater. MS has the same units as k_{eff}. The theoretical MS is the difference between the 95% Lower Confidence Level and the USL The former is a calculation of the lower tolerance limit using 95% as a percent of cases and the latter is the same calculation with 99.9% as a percent of cases. Then some define the real MS (as compared to the theoretical MS) as the calculation using the minimum USL. If you only have one set of data, the USL and the USL_{min} are the same.

An accepted method of validating a computer for KENO criticality involves calculating the Upper Safety Limit (USL), also known as the 95/99.9 lower tolerance limit. The user selects a confidence level, usually 95%. Then the user chooses the percent of benchmark cases (keff = 1.0) which, when run on that computer, $k_{eff} + 2\,\sigma$ must fall above that upper safety limit. This is usually 99.9%
The confidence level is P1 and the percent of benchmark cases is P2 (they are actually probabilities). A statistical analysis is conducted on the KENO output, i.e., k_{eff} and sigma, from each run. The mean k_{eff} and the standard deviation are calculated.
The area under a statistical 'normal' curve can also be referred to as a probability.
Consider a case where P1 is .95 and P2 is .999 The abscissa of the normal curve runs from -4 to +4 and the point where the area under the curve to the left is .95 or 95% of the total area is called a critical point. 'Critical' here does not mean a self-sustaining nuclear reaction but rather is a mathematical term. In this case it is 1.64485.
The critical point corresponding to 99.9% is 3.0902
Knowing these two critical points, one may now calculate the one-sided Tolerance Interval which will be used to calculate the USL and also the Margin of Subcriticality by the equation below given by M. G. Natrella[6].
Each one-sided Tolerance Interval is a function of sample number N, confidence level critical value Zg, and number of cases critical value Zp.

For the USL calculation, Zg is 1.64485 corresponding to a P1 of 0.95
Zp is 3.0902 corresponding to a P2 of 0.999
N is the number of cases run
USL = $\bar{x} - T^*\sigma$
where $\bar{x}$ is the mean keff
T is the 95/99.9 one-sided Tolerance Interval (see below)
and σ is the standard deviation

For the Margin of Subcriticality, Zg is 1.64485 corresponding to a P1 of 0.95
Zp is 1.64485 corresponding to a P2 of 0.95
N is the number of cases run
$T_{95/99.9}$ is brought in from the USL calc above
Theoretical Margin of Subcriticality = $(\bar{x} - T_{95/95}{}^*s) - (\bar{x} - T_{95/99.9}{}^*s)$
where $(\bar{x} - T_{95/95}{}^*s)$ is the 95% Lower Confidence Limit, LCL
and $(\bar{x} - T_{95/99.9}{}^*s)$ is the Upper Safety Limit, USL

and where T = (Zp+(Zp**2-A*B)**0.5)/A
A = 1-((Zg**2)/2*(N-1)))
B = Zp**2-(Zg**2)/N
These equations can easily be solved as a spreadsheet calculation.

Figure D1 shows the area under a normal curve left of x as F(x).
Table 1 gives the area under a normal curve as a function of x. x is measured from the center zero. F(x) must be interpolated between two points and 0.5 added if x is right of the mean at x equal 0, as it is for the 0.95 as well as the 0.999 critical point.
Table 2 shows the calculation of the One-Sided Tolerance Interval $T_{95/95}$.
Table 3 shows the calculation of the One-Sided Tolerance Interval $T_{95/99.9}$.

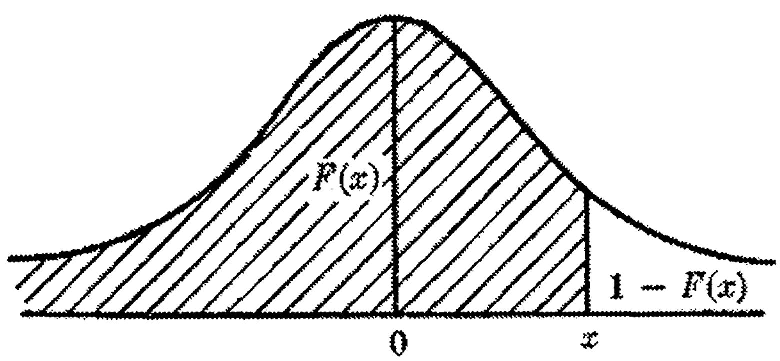

Figure D1 - Normal Curve

Sheet No. 27/30
Calc. No. BUF-04-032
Rev. No. 0

Table 1 - Area Under the Normal Curve

Area under the Normal Curve from 0 to x										
X	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0.00000	0.00399	0.00798	0.01197	0.01595	0.01994	0.02392	0.02790	0.03188	0.03586
0.1	0.03983	0.04380	0.04776	0.05172	0.05567	0.05962	0.06356	0.06749	0.07142	0.07535
0.2	0.07926	0.08317	0.08706	0.09095	0.09483	0.09871	0.10257	0.10642	0.11026	0.11409
0.3	0.11791	0.12172	0.12552	0.12930	0.13307	0.13683	0.14058	0.14431	0.14803	0.15173
0.4	0.15542	0.15910	0.16276	0.16640	0.17003	0.17364	0.17724	0.18082	0.18439	0.18793
0.5	0.19146	0.19497	0.19847	0.20194	0.20540	0.20884	0.21226	0.21566	0.21904	0.22240
0.6	0.22575	0.22907	0.23237	0.23565	0.23891	0.24215	0.24537	0.24857	0.25175	0.25490
0.7	0.25804	0.26115	0.26424	0.26730	0.27035	0.27337	0.27637	0.27935	0.28230	0.28524
0.8	0.28814	0.29103	0.29389	0.29673	0.29955	0.30234	0.30511	0.30785	0.31057	0.31327
0.9	0.31594	0.31859	0.32121	0.32381	0.32639	0.32894	0.33147	0.33398	0.33646	0.33891
1	0.34134	0.34375	0.34614	0.34849	0.35083	0.35314	0.35543	0.35769	0.35993	0.36214
1.1	0.36433	0.36650	0.36864	0.37076	0.37286	0.37493	0.37698	0.37900	0.38100	0.38298
1.2	0.38493	0.38686	0.38877	0.39065	0.39251	0.39435	0.39617	0.39796	0.39973	0.40147
1.3	0.40320	0.40490	0.40658	0.40824	0.40988	0.41149	0.41308	0.41466	0.41621	0.41774
1.4	0.41924	0.42073	0.42220	0.42364	0.42507	0.42647	0.42785	0.42922	0.43056	0.43189
1.5	0.43319	0.43448	0.43574	0.43699	0.43822	0.43943	0.44062	0.44179	0.44295	0.44408
1.6	0.44520	0.44630	0.44738	0.44845	0.44950	0.45053	0.45154	0.45254	0.45352	0.45449
1.7	0.45543	0.45637	0.45728	0.45818	0.45907	0.45994	0.46080	0.46164	0.46246	0.46327
1.8	0.46407	0.46485	0.46562	0.46638	0.46712	0.46784	0.46856	0.46926	0.46995	0.47062
1.9	0.47128	0.47193	0.47257	0.47320	0.47381	0.47441	0.47500	0.47558	0.47615	0.47670
2	0.47725	0.47778	0.47831	0.47882	0.47932	0.47982	0.48030	0.48077	0.48124	0.48169
2.1	0.48214	0.48257	0.48300	0.48341	0.48382	0.48422	0.48461	0.48500	0.48537	0.48574
2.2	0.48610	0.48645	0.48679	0.48713	0.48745	0.48778	0.48809	0.48840	0.48870	0.48899
2.3	0.48928	0.48956	0.48983	0.49010	0.49036	0.49061	0.49086	0.49111	0.49134	0.49158
2.4	0.49180	0.49202	0.49224	0.49245	0.49266	0.49286	0.49305	0.49324	0.49343	0.49361
2.5	0.49379	0.49396	0.49413	0.49430	0.49446	0.49461	0.49477	0.49492	0.49506	0.49520
2.6	0.49534	0.49547	0.49560	0.49573	0.49585	0.49598	0.49609	0.49621	0.49632	0.49643
2.7	0.49653	0.49664	0.49674	0.49683	0.49693	0.49702	0.49711	0.49720	0.49728	0.49736
2.8	0.49744	0.49752	0.49760	0.49767	0.49774	0.49781	0.49788	0.49795	0.49801	0.49807
2.9	0.49813	0.49819	0.49825	0.49831	0.49836	0.49841	0.49846	0.49851	0.49856	0.49861
3	0.49865	0.49869	0.49874	0.49878	0.49882	0.49886	0.49889	0.49893	0.49896	0.49900
3.1	0.49903	0.49906	0.49910	0.49913	0.49916	0.49918	0.49921	0.49924	0.49926	0.49929
3.2	0.49931	0.49934	0.49936	0.49938	0.49940	0.49942	0.49944	0.49946	0.49948	0.49950
3.3	0.49952	0.49953	0.49955	0.49957	0.49958	0.49960	0.49961	0.49962	0.49964	0.49965
3.4	0.49966	0.49968	0.49969	0.49970	0.49971	0.49972	0.49973	0.49974	0.49975	0.49976
3.5	0.49977	0.49978	0.49978	0.49979	0.49980	0.49981	0.49981	0.49982	0.49983	0.49983
3.6	0.49984	0.49985	0.49985	0.49986	0.49986	0.49987	0.49987	0.49988	0.49988	0.49989
3.7	0.49989	0.49990	0.49990	0.49990	0.49991	0.49991	0.49992	0.49992	0.49992	0.49992
3.8	0.49993	0.49993	0.49993	0.49994	0.49994	0.49994	0.49994	0.49995	0.49995	0.49995
3.9	0.49995	0.49995	0.49996	0.49996	0.49996	0.49996	0.49996	0.49996	0.49997	0.49997
4	0.49997	0.49997	0.49997	0.49997	0.49997	0.49997	0.49998	0.49998	0.49998	0.49998

Table 2 - Calculating the One-Sided Tolerance Interval $T_{95/95}$

Confidence Probability, P1	Critical Value Zg	Coverage Probability, P2	Critical Value, Zp	A	B	One-Sided Tolerance Interval, $T_{95/95}$	N
0.95	1.64485	0.95	1.64485	0.8309043	2.4049169	**2.99173678**	9
0.95	1.64485	0.95	1.64485	0.9098156	2.5364358	**2.50116356**	16
0.95	1.64485	0.95	1.64485	0.9549078	2.6182563	**2.19706288**	31
0.95	1.64485	0.95	1.64485	0.9699385	2.6467156	**2.07935307**	46
0.95	1.64485	0.95	1.64485	0.9795035	2.6651505	**1.99395129**	67
0.95	1.64485	0.95	1.64485	0.9819631	2.6699324	**1.96978566**	76
0.95	1.64485	0.95	1.64485	0.9880286	2.6817988	**1.90394254**	114
0.95	1.64485	0.95	1.64485	0.9895134	2.6847197	**1.8859076**	130
0.95	1.64485	0.95	1.64485	0.9933361	2.6922691	**1.83371431**	204
0.95	1.64485	0.95	1.64485	0.993619	2.6928295	**1.82939579**	213
0.95	1.64485	0.95	1.64485	0.9953191	2.6962021	**1.80143737**	290
0.95	1.64485	0.95	1.64485	0.9954757	2.6965131	**1.79865258**	300

Table 3 - Calculating the One-Sided Tolerance Interval $T_{95/99.9}$

Confidence Probability, P1	Critical Value Zg	Coverage Probability, P2	Critical Value Zp	A	B	One-Sided Tolerance Interval, $T_{95/99.9}$	N
0.95	1.64485	0.999	3.0902	0.8309043	9.2487214	**5.36244601**	9
0.95	1.64485	0.999	3.0902	0.9098156	9.3802403	**4.50387452**	16
0.95	1.64485	0.999	3.0902	0.9549078	9.4620608	**3.98687313**	31
0.95	1.64485	0.999	3.0902	0.9699385	9.4905201	**3.79076905**	46
0.95	1.64485	0.999	3.0902	0.9795035	9.508955	**3.65007113**	67
0.95	1.64485	0.999	3.0902	0.9819631	9.5137369	**3.61051154**	76
0.95	1.64485	0.999	3.0902	0.9880286	9.5256033	**3.50330967**	114
0.95	1.64485	0.999	3.0902	0.9895134	9.5285243	**3.47409814**	130
0.95	1.64485	0.999	3.0902	0.9933361	9.5360736	**3.38993549**	204
0.95	1.64485	0.999	3.0902	0.993619	9.536634	**3.38299707**	213
0.95	1.64485	0.999	3.0902	0.9953191	9.5400066	**3.3381717**	290
0.95	1.64485	0.999	3.0902	0.9954757	9.5403176	**3.33371587**	300

References and Data Available:
1. Scale 4.4 Manual
2. PSR-6
3. PSR-18
4. NCSE-001
5. NCSE-002
6. Validation Reports in BUF Calc files

Design Criteria: See WVDP-162

Assumptions: See individual Cases and Attachments

Prepared by:	C. Alvin Sweet Signature	3-17-04 Date
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Calculation Cover Page

Job No: **39399976 / 06354** Calculation No: **BUF-04-033/Rev. 0** Date: **March 1, 2004**

**VALIDATION OF THE SCALE-PC (VERSION 4.4a)
COMPUTER CODE PACKAGE FOR URANIUM SYSTEMS ENRICHED IN THE U-235 ISOTOPE**

Problem Statement and Calculation Objectives: This calculation covers the validation of the SCALE- PC (Version 4.4a) computer code package for Uranium systems enriched in the U-235 isotope at West Valley Demonstration Plant.

(IBM P4-3060 Personal Computer - Serial No. 412-56-6368-1A)

TABLE OF CONTENTS

1.0 INTRODUCTION

The SCALE-PC (Version 4.4a) computer code package was validated for use on the URS Personal Computer (Serial No. 412-56-6368-1A). These validation calculations were performed for low-enriched, intermediate-enriched, and high-enriched uranium systems using the 27-group cross section library. It should be noted that only uranium systems enriched in the U-235 isotope were considered. The systems modeled contained UO_2, U_3O_8, UO_2F_2 solution, UNH solution, U-metal, U-metal rods in UO_2F_2 solution, UF_4, and U(nat)O_2-PuO_2 rods. The various systems were also modeled using different materials, geometries, arrays, and reflectors.

The uranium systems analyzed for this report range in enrichments from 0.71 to 97.67 weight percent U-235. Therefore, this report develops limits for systems containing uranium enriched up to 100% in the U-235 isotope.

When performing the validation, the American National Standards Institute guidance in ANSI/ANS-8.1[1] was considered. The standard requires that calculational methods used for criticality safety analyses are validated and that any bias be determined by correlating the results of critical experiments with calculations.

2.0 DESCRIPTION OF THE SCALE-4.4 SYSTEM

SCALE-4.4 is a modular code system for performing Standardized Computer Analyses for Licensing Evaluations. This system consists of modules to prepare cross-section sets and modules to perform both Monte-Carlo and discrete ordinates neutronics calculations using these cross-section sets. The calculations performed in this validation involved the use of the Monte-Carlo code KENO-Va, developed at the Oak Ridge National Laboratory (ORNL)[2].

A set of Criticality Safety Analysis Sequence (CSAS) control modules is used in the SCALE-4.4 system to call the various functional modules. Because this validation was performed for Monte-Carlo calculations, only the control and functional modules that pertain to the Monte-Carlo calculations are described in this section. For a complete description of the SCALE-4.4 and KENO-Va and KENO-VI system and mathematical methods used therein, refer to the SCALE-4.4 Manual[3].

SCALE.EXE is a frozen version of a system of nuclear criticality safety codes available in the SCALE-4.4 PC package (RSIC #C00545/MNYCP00). The sequence being validated is the CSAS25 sequence documented in the SCALE-4.4 manual. This sequence uses control module CSAS.EXE and program modules O0O008.EXE (BONAMI-2), O0O002.EXE (NITAWL), and O0O009.EXE (KENO-Va). The 27-group ENDF/B-IV cross-section master library, stored in data set FT82F001, was used for all calculations.

2.1 CSAS25 and CSAS4

The CSAS25 and CSAS4 control modules call the functional modules in the order BONAMI (Bondarenko AMPX Interpolator), NITAWL (Nordheim Integral Treatment AMPX Working Library), and KENO-Va. The only difference between the CSAS25 module and the CSAS4 module is that the CSAS4 module allows the user to perform dimensional searches for various geometries and array pitches for given k-effective values. Because the same cross sections (prepared by BONAMI and NITAWL) are used for each KENO-Va run, validations performed using the CSAS25 control module will apply to calculations performed using the CSAS4 module.

2.2 BONAMI

The primary purpose of the BONAMI functional module is to select the required cross-sections and to create a smaller master cross-section library to be processed by NITAWL. This module also performs resonance self-shielding calculations for nuclides that have Bondarenko data associated with their cross sections.

2.3 NITAWL

The NITAWL functional module treats the resonance region cross sections for resonance absorbers. This treatment is based upon the Nordheim Integral Transform method. The user has the option of treating the resonance parameters in the manner most appropriate for the problem detail. The three methods used are as follows (with description):

1. **INFHOMMEDIUM** This option treats the material as an infinite homogeneous mixture.
2. **LATTICECELL** This option treats a multiple repeated cell for resonance self-shielding correction.
3. **MULTIREGION** This option treats a single cell for resonance self-shielding correction.

2.4 KENO

The KENO code uses the integral form of the neutron transport equation to solve for an eigenvalue k, which is the multiplication constant or k-effective (k_{eff}). KENO uses a Monte-Carlo technique to determine neutron mean free path, absorption, fission, scattering, and leakage. The k-effective value indicates the degree to which the system being analyzed is subcritical, critical, or supercritical.

The KENO-Va code is a substantial revision of the KENO-IV code. The KENO-Va code allows for holes, array of arrays, enhanced plotting capabilities, and variable chords for hemi-cylinders and hemispheres. The primary purpose of the KENO-Va code is to calculate the k-effective value. However, the code also calculates fissions, fission densities, neutron fluxes, neutron lifetimes, and energy and region dependent absorptions.

The KENO-VI code is a substantial revision of the KENO-Va code. KENO-VI is not used in this validation. The KENO-VI code allows for the following: intersecting geometry regions; hexagonal as well as cuboidal arrays; regions, holes, arrays, and units rotated to any angle and truncated to any position; and the use of an array boundary that intersects the array. KENO-VI maintains all the flexibility and options of KENO-Va plus a variety of new options. In KENO-VI, units can be constructed using both the simple geometric shapes provided and the tailored geometric shapes constructed using quadratic equations. It includes the new 2-D color plotting capability that has been added to KENO-Va. A new SCALE Criticality Safety Analysis Sequence, CSAS6, has been added for running KENO-VI. It should be noted that a KENO-VI problem that can be modeled with KENO-Va will typically run twice as long as the same problem using KENO-VA. KENO-VI/(CSAS26) would be validated in a separate document.

2.5 27-GROUP CROSS-SECTION LIBRARY FROM ENDF/B-IV

The 27-Group ENDF/B-IV cross section library was created in 1981 from the 218 Group ENDF/B-IV cross section library set. Before that time, the 16 Group Hansen-Roach, Knight-Modified cross section set was most often used. The 27-group set is considered an improvement because more thermal groups are available and because upscatter is included.

2.6 44-GROUP and 238-GROUP CROSS-SECTION LIBRARIES FROM ENDF/B-V

The 123GROUP and 218GROUP cross-section-library keywords were replaced with 44GROUP and 238GROUP. The former libraries, which were the least used of the standard SCALE libraries, were removed as defaults so the new ENDF/B-V libraries, which give more accurate results, could be accessed directly via keyword input.

3.0 DISCUSSION OF RESULTS

A total of 290 (114 low-enriched, 46 intermediate-enriched, and 130 high-enriched) uranium benchmark experiments were used to validate the SCALE-4.4 CSAS4 and CSAS25 modules.

Most of the low-enriched SCALE-4.4 inputs were the same as those used in the validation performed at Oak Ridge (Refer to Reference 4, Tables 1 to 3 and A.1 to A.3). It should be noted that the inputs CAR04 and CAR06 were modified slightly in order for them to run on the PC. The modifications were to unit 11 in CAR04 and unit 37 in CAR06. One or more dimensions were decreased by 0.01cm or less. The input series CAE01 to CAE13 was based on Reference 5. It should also be noted that the inputs CAE01 to CAE06 are models of mixed oxide systems (i.e., U(nat)O_2-PuO_2) and the composition of the Pu in the models is 91.579% Pu-239, 7.683% Pu-240, 0.707% Pu-241, and 0.031% Pu-242.

A previous validation was performed for intermediate-enriched uranium systems by R. A. Bond[6] and this validation report used the 46 KENO-Va models generated by Mr. Bond. The KENO-Va models were of critical experiments based on a report published in March 1960, by Dounreay Experimental Reactor Establishment[7]. These experiments involved critical height measurements with 30.3% enriched uranyl fluoride solutions (UO_2F_2) in 8-inch, 12-inch, and 16-inch diameter cylindrical tanks. The experiments were performed using various reflectors that include combinations of water, stainless steel, aluminum, and cadmium.

The high-enriched SCALE-4.4 inputs were the same as those used in the validation performed at Oak Ridge (Refer to Reference 4, Tables 4 to 6 and A.4 to A.6), with the exception of cases CAS30 through CAS59. These cases were replaced by CAM30 through CAM59. The CAM30 through CAM59 cases contained improved biasing and more realistic geometry, such as inclusion of the room of the experiment as reflector. It should also be noted that the CAE cases used in this report are the same as the corresponding CAS cases listed in Reference 4.

It was also discovered during the issuance of a previous validation report that the default time allotted for each generation (TBA) was insufficient for several high-enriched cases (i.e., CAA17, CAA18, CAA21, CAA22, and CAS10). When this was increased for each of these cases, the individual results changed slightly. These new results were used in the validation.

Roger D. Carter, a consultant for Nuclear Fuel Services (NFS), sent NFS a list, with explanations, of the validation cases with duplication, incorrect modeling, or differences in experimental k-effective, etc. (Refer to References 8 and 9). This information was used to omit faulty or questionable cases from the statistical analysis in the validation and to identify more accurate inputs such as the CAM30 through CAM59 cases mentioned above.

Mr. Carter also indicated that the experimental k values for various validation experiments were not unity[8] and that the calculated k-effective values should be normalized to the experimental value using the formula

$k_{report} = k_{calc}/k_{exp}$, where the subscripts "report," "calc," and "exp" refer to the k values reported, calculated, and experimental, respectively.

The calculations performed for the URS validation were made using 103 generations with 300 neutrons per generation. According to generally accepted practice, the k-effective values for at least the first three generations were not included in the mean k-effective calculation because the poor spatial distribution of the neutrons would tend to bias the results. The results of the low-enriched calculations are given in Appendix A, the results of the intermediate-enriched calculations are given in Appendix B, and the results of the high-enriched calculations are given in Appendix C. Footnotes in Appendix C indicate where moderation other than water was used and where the k-effective values are calculated as recommended by Mr. Carter. The data was also determined to be normally distributed.

The statistical analysis procedure consisted of determining a mean and a standard deviation for the set of k-effective values being analyzed. A one-sided lower tolerance limit was then determined such that one can predict with 95% confidence that 99.9% of the k-effective values for critical systems will lie above this limit. One can then be confident that a k-effective below this limit represents a subcritical condition. For this application, the lower tolerance limit was designated the Upper Safety Limit (USL). The statistical method used is explained in Reference 10 and the factors for the one-sided tolerance limits (tolerance limit factors) are given in Reference 11. Refer to Appendix D for more details regarding the USL calculation. Refer to Appendix D in BUF-04-032 for more details regarding the One-Sided Tolerance Interval calculation. This technique is similar to the technique proposed by H. R. Dyer[11], except that the data was pooled rather than being used with a correlating parameter (e.g., moderating ratio, average energy group causing fission, or ratio of total fissions to thermal fissions). It was concluded that the validation data did not correlate well with other parameters. The bias is defined as the difference between the average and the true value or, as in the case of this validation, the difference between the arithmetic mean of calculated k-effective values (for various benchmark groupings) and the experimental k-effective value (i.e., k_{calc} minus k_{exp}). It should also be noted that the value of the USL contains the bias, for example, the bias is included in the expression

"$\bar{X} - T_{(n,\gamma,P)}s$").

Statistical analyses were performed for various groupings of validation cases. Refer to the table below for these results:

TABLE OF STATISTICAL ANALYSES

Grouping	No. of Cases	Mean k-eff	Standard Deviation	Bias	Tolerance Limit Factor[10]	USL
Entire Set (LEU/IEU/HEU)	290	1.0024	0.0096	(+)0.0024	3.3382	0.9705
Low-enriched cases	114	0.9993	0.0089	(-)0.0007	3.5033	0.9681
Low-enriched metal cases (thermal)	31	0.9978	0.0090	(-)0.0022	3.9869	0.9619
Low-enriched non-metal	67	0.9990	0.0095	(-)0.0010	3.6501	0.9643
LEU-HEU/Pu	16	1.0035	0.0062	0.0035	4.5039	0.9756
Intermediate-enriched cases	46	1.0078	0.0053	(+)0.0078	3.7908	0.9877
High-enriched cases	130	1.0031	0.0105	(+)0.0031	3.4741	0.9671
High-enriched metal cases (non-thermal)	16	1.0024	0.0087	(+)0.0024	4.5039	0.9679
High-enriched non-metal	114	1.0032	0.0109	(+)0.0032	3.5033	0.9658

For safety analysis purposes, a calculated k-effective plus two standard deviations must lie below the USL (i.e., $k_{eff} + 2\sigma < USL$). This statistical method for code validation allows the USL to be established such that there is a high degree of confidence that a calculated result which satisfies the acceptance criteria is indeed subcritical.

Although a margin of subcriticality is not specifically determined by the technique, a margin can be defined as the difference between the one-sided 95% lower confidence limit and the USL (also called the 95/99.9 lower tolerance limit)[11,12]. The one-sided 95% lower confidence limit is defined by the equation

$$\bar{x} - T_p s$$

where K_p is read from a table of the inverse normal probability distribution. The value of T_p varies with the number of samples[13]. Refer to the following table for calculated margins of subcriticality:

TABLE OF STATISTICAL ANALYSES				
Grouping	95% Lower Confidence Limit	Tolerance Limit Factor	USL	Margin of Subcriticality
Entire Set (LEU/IEU/HEU)	0.9852	1.8014	0.9705	0.01470
Low-enriched Cases	0.9824	1.9039	0.9681	0.01423
Low-enriched metal/Excluding HEU/Pu	0.9780	2.1971	0.9619	0.01611
Low-enriched Non-metal/Excl HEU/PU	0.9801	1.9940	0.9643	0.01573
Low-enriched High-enriched/Pu	0.9880	2.5012	0.9756	0.01242
Intermediate-enriched cases	0.9968	2.0794	0.9877	0.00907
High-enriched Cases	0.9835	1.8859	0.9671	0.01640
High-enriched Metal cases (non-thermal)	0.9833	2.5012	0.9679	0.01540
High-enriched Non-metal	0.9828	1.9039	0.9658	0.01700

According to generally accepted practice throughout the criticality safety community, the maximum allowable calculated k-effective plus two standard deviations shall be less than or equal to 0.95 (i.e., $k_{eff} + 2\sigma \leq 0.95$). Since the bias is included in the USL, and since all USLs are greater than 0.95, the real margin of subcriticality is the difference between the one-sided lower 95% confidence limit and 0.95. Refer to the following table for the recalculated margins of subcriticality:

MARGINS OF SUBCRITICALITY		
Grouping	95% Lower Confidence Level	Margin of Subcriticality
Entire Set (LEU/IEU/HEU)	0.9852	0.03520
Low-enriched Cases	0.9824	0.03236
Low-enriched metal cases (thermal)	0.9780	0.02803
Low-enriched non-metal	0.9801	0.03006
LEU-HEU/Pu	0.9880	0.03799
Intermediate-enriched cases	0.9968	0.04678
High-enriched cases	0.9835	0.03350
High-enriched metal cases (non-thermal)	0.9833	0.03330
High-enriched non-metal	0.9828	0.03280

According to generally accepted practice, the margin of subcriticality should be at least 0.02. When recalculated, the margin of subcriticality for all groupings is at least 0.028.

For uranium-bearing materials other than those modeled in these calculations and for other U-235 enrichments, a (-)0.01 Δk uncertainty is applied to the USL calculated for the entire data set. Δk is all other unknown uncertainties. This results in a lower USL of **0.9678 - 0.010025 = 0.9578**. Since the bias is included in the USL, and since the USL is greater than 0.95, the maximum allowable calculated k-effective plus two standard deviations for these materials shall be less than or equal to 0.95 (i.e., $k_{eff} + 2\sigma \leq 0.95$).

4.0 CONCLUSIONS

The SCALE-PC (Version 4.4) computer code package accurately calculates a broad range of critical experiments and can be used with great confidence for the design and criticality safety analysis of uranium-bearing systems.

This validation meets the criteria for "validation of a calculational method" specified in Reference 1 (Section 4.3) as follows:

Types of systems that can be modeled:

Systems enriched in the U-235 isotope
All chemical forms of uranium compounds
All physical forms of uranium compounds
Moderated and unmoderated systems
Single units and arrays
All geometries

Range of parameters which may be treated:

Enrichment: Any (wt.% U-235 only)
Moderators: Any*
Degrees of Moderation: All
Reflectors: Any*
Concentration/Density: U Metal at theoretical density to infinitely dilute solutions

* When available, additional benchmark cases will be analyzed to increase the confidence in using the code and cross sections for systems involving unique or uncommon moderators/reflectors.

Bias in the results produced by this method:

The lowest mean k-effective for any set of cases occurred for the 31 low-enriched metal uranium cases, which had a bias of (-)0.0022 (i.e., $k_{calculated}$ minus $k_{experimental}$).

Margin of Subcriticality:

The smallest margin of subcriticality for any set of cases occurred for the 31 low-enriched metal uranium cases, which had a margin of subcriticality of 0.02803.

Additionally, since all USLs are greater than 0.95, and since the bias is included in the USL, a system can be considered acceptably subcritical if a converged k-effective value plus two standard deviations is less than or equal to 0.95 (i.e., $k_{eff} + 2\sigma \leq 0.95$).

Note: Although this validation utilized the default values of NPG=300 and GEN=103 (resulting in tracking 30,000 neutron histories after skipping the first three generations), increasing the number of neutrons and/or the number of generations (for a calculation) does not violate the basis of acceptable subcriticality as documented in this validation report (i.e., $k_{eff} + 2\sigma \leq 0.95$). While tracking more neutron histories will permit better convergence of the calculations, it also tends to lower the standard deviation of the calculation. However, as stated previously, this does not violate the basis of acceptable subcriticality.

5.0 REFERENCES

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8) Roger D. Carter, Comments on ORNL/CDC/TM-238 Validation Data, Personal Communication to Nuclear Fuel Services, Inc., March 18, 1992.

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12) H. R. Dyer, W. C. Jordan, V. R. Cain, "A Technique for Code Validation for Criticality Safety Calculations," Transactions of the American Nuclear Society, 63, 238, (June 1991).

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APPENDIX A
Summary of PC Scale-4.4/KENO-Va
Low-Enriched Uranium Validation Calculations

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
CAA01	0.9935	0.0019	Metal Rods in H2O	Sq. Pitch Array	H2O,Plexi	4.89	3.610e-06
CAA02	0.9956	0.0020	Metal Rods in H2O	Sq. Pitch Array	H2O	4.89	4.000e-06
CAA03	0.9906	0.0020	Metal Rods in H2O	Sq. Pitch Array	H2O	4.89	4.000e-06
CAA04	0.9891	0.0019	Metal Rods in H2O	Sq. Pitch Array	H2O	4.89	3.610e-06
CAA05	0.9827	0.0019	Metal Rods in H2O	Sq. Pitch Array	H2O	4.89	3.610e-06
CAA06	0.9957	0.0020	Metal Rods in H2O	Sq. Pitch Array	H2O,Plexi,Pb	4.89	4.000e-06
CAA07	0.9895	0.0023	Metal Rods in H2O + SS Plate	Sq. Pitch Array	H2O,Plexi,Pb	4.89	5.290e-06
CAA08	0.9941	0.0020	Metal Rods in H2O	Sq. Pitch Array	H2O,Plexi,Pb	4.89	4.000e-06
CAA09	0.9946	0.0021	Metal Rods in H2O + SS Plate	Sq. Pitch Array	H2O,Plexi,Pb	4.89	4.410e-06
CAA10	1.0012	0.0019	Metal Rods in H2O+Boral Plate	Sq. Pitch Array	H2O,Plexi,Pb	4.89	3.610e-06
CAA11	0.9951	0.0021	Metal Rods in H2O + Cd Plate	Sq. Pitch Array	H2O,Plexi,Pb	4.89	4.410e-06
CAA12	0.9894	0.0018	Metal Rods in UO2F2	Sq. Pitch Array	Plexiglas/UO2F2	4.89	3.240e-06
CAA13	0.9928	0.0018	Metal Rods in UO2F2	Sq. Pitch Array	Plexiglas/UO2F2	4.89	3.240e-06
CAA14	0.9891	0.0018	Metal Rods in UO2F2	Sq. Pitch Array	Plexiglas/UO2F2	4.89	3.240e-06
CAA15	0.9964	0.0019	Metal Rods in UO2F2	Sq. Pitch Array	Plexiglas/UO2F2	4.89	3.610e-06
CAA16	0.9884	0.0018	Metal Rods in UO2F2	Sq. Pitch Array	Plexiglas/UO2F2	4.89	3.240e-06
CAA17	0.9905	0.0017	Metal Rods in UO2F2	Sq. Pitch Array	Plexiglas/UO2F2	4.89	2.890e-06
CAA18	0.9879	0.0016	Metal Rods in UO2F2	Sq. Pitch Array	Plexiglas/UO2F2	4.89	2.560e-06
CAA19	0.9871	0.0020	U3O8+Sterotex	Cuboid	None	4.89	4.000e-06
CAA20	1.0045	0.0022	U3O8+Sterotex	Cuboid	None	4.89	4.840e-06
CAA21	1.0072	0.0015	U3O8+Sterotex	Cuboid	None	4.89	2.250e-06
CAA22	0.9971	0.0016	U3O8+Sterotex	Cuboid	None	4.89	2.560e-06
CAA23	0.9826	0.0020	U3O8+Sterotex	Cuboid	H2O-Paraffin	4.89	4.000e-06

APPENDIX A
Summary of PC Scale-4.4/KENO-Va
Low-Enriched Uranium Validation Calculations
(continued)

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
CAA24	0.9877	0.0021	U3O8+Sterotex	Cuboid	H2O-Paraffin	4.89	4.410e-06
CAA25	0.9944	0.0017	U3O8+Sterotex	Cuboid	H2O-Paraffin	4.89	2.890e-06
CAA26	1.0051	0.0014	U3O8+Sterotex	Cuboid	H2O-Paraffin	4.89	1.960e-06
CAA27	0.9923	0.0021	U3O8+Sterotex	Cuboid	H2O-Paraffin	4.89	4.410e-06
CAA28	0.9689	0.0022	U3O8+Sterotex	Cuboid	H2O-Paraffin	4.89	4.840e-06
CAA29	0.9950	0.0018	U3O8+Sterotex	Cuboid	H2O-Paraffin	4.89	3.240e-06
CAA30	0.9929	0.0017	UO2F2	Cylinder	None (SS)	4.89	2.890e-06
CAA31	0.9931	0.0019	UO2F2	Cuboid	None (Al)	4.89	3.610e-06
CAA32	0.9971	0.0016	UO2F2	Cylinder	None (SS)	4.89	2.560e-06
CAA33	0.9903	0.0015	UO2F2	Hemisphere	None (Al)	4.89	2.250e-06
CAA34	0.9982	0.0014	UO2F2	Cylinder	Plexiglas	4.89	1.960e-06
CAA35	1.0000	0.0017	UO2F2	Cylinder	H2O	4.89	2.890e-06
CAA36	1.0033	0.0017	UO2F2	Cuboid	H2O	4.89	2.890e-06
CAA37	0.9956	0.0016	UO2F2	Cylinder	H2O	4.89	2.560e-06
CAA38	0.9929	0.0014	UO2F2	Hemisphere	H2O	4.89	1.960e-06
CAA39	0.9970	0.0013	UO2F2	Cylinder	H2O	4.89	1.690e-06
CAB01	1.0053	0.0017	Metal Annuli/Inserts in H2O	Sq. Pitch Array	H2O-Wood	3.85	2.890e-06
CAB02	1.0077	0.0014	Metal Annuli/Inserts in H2O	Sq. Pitch Array	H2O-Wood	3.85	1.960e-06
CAB03	1.0050	0.0016	Metal Annuli/Inserts in H2O	Sq. Pitch Array	H2O-Wood	3.85	2.560e-06
CAB07	0.9948	0.0016	Metal Annuli/Inserts in H2O	Tri. Pitch Array	H2O-Wood	3.85	2.560e-06
CAB08	1.0016	0.0016	Metal Annuli/Inserts in H2O	Tri. Pitch Array	H2O-Wood	3.85	2.560e-06
CAB09	0.9999	0.0015	Metal Annuli/Inserts in H2O	Tri. Pitch Array	H2O-Wood	3.85	2.250e-06
CAB10	1.0109	0.0016	Metal Annuli in H2O	Sq. Pitch Array	H2O-Wood	3.85	2.560e-06
CAB11	1.0085	0.0016	Metal Annuli in H2O	Sq. Pitch Array	H2O-Wood	3.85	2.560e-06

APPENDIX A
Summary of PC Scale-4.4/KENO-Va
Low-Enriched Uranium Validation Calculations
(continued)

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
CAB12	1.0055	0.0015	Metal Annuli in H2O	Sq. Pitch Array	H2O-Wood	3.85	2.250e-06
CAB13	1.0131	0.0016	Metal Annuli in H2O	Sq. Pitch Array	H2O-Wood	3.85	2.560e-06
CAB14	1.0165	0.0015	Metal Rods in H2O	Sq. Pitch Array	H2O-Wood	3.85	2.250e-06
CAB15	1.0096	0.0016	Metal Rods in H2O	Sq. Pitch Array	H2O-Wood	3.85	2.560e-06
CAB16	0.9987	0.0016	Metal Rods in H2O	Sq. Pitch Array	H2O-Wood	3.85	2.560e-06
CAE01	1.0007	0.0017	UO2-PuO2 Rods in H2O	Sq. Pitch Array	Boron-H2O	0.71	2.890e-06
CAE02	1.0148	0.0015	UO2-PuO2 Rods in H2O	Tri. Pitch Array	Boron-H2O,Pb	0.71	2.250e-06
CAE03	1.0140	0.0015	UO2-PuO2 Rods in H2O	Tri. Pitch Array	Boron-H2O	0.71	2.250e-06
CAE04	0.9965	0.0016	UO2-PuO2 Rods in H2O	Sq. Pitch Array	Boron-H2O	0.71	2.560e-06
CAE05	1.0007	0.0017	UO2-PuO2 Rods in H2O	Tri. Pitch Array	Boron-H2O	0.71	2.890e-06
CAE06	1.0056	0.0018	UO2-PuO2 Rods in H2O	Tri. Pitch Array	H2O,Pb	0.71	3.240e-06
CAE07	0.9992	0.0015	UO2 Rods in H2O	Sq. Pitch Array	Boron-H2O	2.35	2.250e-06
CAE08	0.9941	0.0020	UO2 Rods in H2O	Sq. Pitch Array	Boron-H2O	2.35	4.000e-06
CAE09	1.0049	0.0013	UO2 Rods in H2O	Tri. Pitch Array	Boron-H2O	2.35	1.690e-06
CAE10	0.9926	0.0018	UO2 Rods in H2O	Sq. Pitch Array	H2O,Pb	2.35	3.240e-06
CAE11	0.9964	0.0016	UO2 Rods in H2O	Sq. Pitch Array	H2O	2.35	2.560e-06
CAE12	0.9950	0.0016	UO2 Rods in H2O	Tri. Pitch Array	H2O,Pb	2.35	2.560e-06
CAE13	0.9896	0.0018	UO2 Rods in H2O	Sq. Pitch Array	H2O	2.72	3.240e-06
CAR01	1.0072	0.0017	U3O8-H2O	Cuboid	Plastic	4.46	2.890e-06
CAR02	1.0043	0.0018	U3O8-H2O	Cuboid	Plastic	4.46	3.240e-06
CAR03	0.9919	0.0019	U3O8-H2O	Cuboid	Plastic	4.46	3.610e-06
CAR04PC	1.0151	0.0018	U3O8-H2O	Cuboid	Concrete	4.46	3.240e-06
CAR05PC	1.0024	0.0016	U3O8-H2O	Cuboid	Concrete	4.46	2.560e-06
CAR06PC	0.9956	0.0027	U3O8-H2O/HE Metal	Cuboid/Sphere	Plastic	4.46	7.290e-06

APPENDIX A
Summary of PC Scale-4.4/KENO-Va
Low-Enriched Uranium Validation Calculations
(continued)

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
CAR07	1.0034	0.0021	U3O8-H2O/HE UNH	Cuboid/Cuboid	Plastic	4.46	4.410e-06
CAR08	1.0017	0.0026	U3O8-H2O/HE UNH	Cuboid/Cuboid	Plastic	4.46	6.760e-06
CAR09	1.0051	0.0018	U3O8-H2O/HE UNH	Cuboid/Cuboid	Plastic	4.46	3.240e-06
CAR10	1.0050	0.0029	U3O8-H2O/HE UNH	Cuboid/Cuboid	Concrete	4.46	8.410e-06
CAR11	1.0053	0.0016	U3O8-H2O	Cuboid	Plastic	4.46	2.560e-06
CAR12	1.0176	0.0018	U3O8-H2O	Cuboid	Plastic	4.46	3.240e-06
CAR13	1.0107	0.0018	U3O8-H2O	Cuboid	Plastic	4.46	3.240e-06
CAR14	1.0095	0.0019	U3O8-H2O/HE UNH	Cuboid/Cuboid	Plastic	4.46	3.610e-06
CAR15	1.0005	0.0028	U3O8-H2O/HE UNH	Cuboid/Cuboid	Plastic	4.46	7.840e-06
CAR16	1.0028	0.0021	U3O8-H2O/HE UNH	Cuboid/Cuboid	Plastic	4.46	4.410e-06
CAR17	1.0041	0.0019	U3O8-H2O	Cuboid	Plastic	4.46	3.610e-06
CAR18PC	1.0076	0.0019	U3O8-H2O	Cuboid	Plastic	4.46	3.610e-06
CAR19	1.0037	0.0018	U3O8-H2O/HE Metal	Cuboid/Sphere	Plastic	4.46	3.240e-06
CAR20	0.9968	0.0019	U3O8-H2O/HE Metal	Cuboid/Sphere	Plastic	4.46	3.610e-06
CAS04	0.9884	0.0014	UF4-Paraffin	Cuboid	None	1.40	1.960e-06
CAS05	0.9892	0.0013	UF4-Paraffin	Cuboid	None	1.40	1.690e-06
CAS06	0.9841	0.0014	UF4-Paraffin	Cuboid	None	1.40	1.960e-06
CAS11	0.9961	0.0019	UF4-Paraffin	Cuboid	Paraffin-Plexi	2.00	3.610e-06
CAS12	0.9974	0.0016	UF4-Paraffin	Cuboid	None	2.00	2.560e-06
CAS13	0.9982	0.0019	UF4-Paraffin	Cuboid	Paraffin-Plexi	2.00	3.610e-06
CAS14	0.9974	0.0015	UF4-Paraffin	Cuboid	None	2.00	2.250e-06
CAS15	0.9960	0.0020	UF4-Paraffin	Cuboid	Paraffin-Plexi	2.00	4.000e-06
CAS16	0.9929	0.0021	UF4-Paraffin	Cuboid	Paraffin-Plexi	2.00	4.410e-06
CAS17	0.9931	0.0019	UF4-Paraffin	Cuboid	Plexi, Poly	2.00	3.610e-06

APPENDIX A
Summary of PC Scale-4.4/KENO-Va
Low-Enriched Uranium Validation Calculations
(continued)

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
CAS18	0.9885	0.0016	UF4-Paraffin	Cuboid	None	2.00	2.560e-06
CAS19	0.9835	0.0016	UF4-Paraffin	Cuboid	Plexi, Poly	2.00	2.560e-06
CAS20	0.9871	0.0011	UF4-Paraffin	Cuboid	None	2.00	1.210e-06
CAS21	1.0117	0.0022	UF4-Paraffin	Cuboid	Paraffin-Plexi	3.00	4.840e-06
CAS22	1.0051	0.0025	UF4-Paraffin	Cuboid	Paraffin-Plexi	3.00	6.250e-06
CAS23	1.0084	0.0025	UF4-Paraffin	Cuboid	Paraffin-Plexi	3.00	6.250e-06
CAS24	1.0114	0.0023	UF4-Paraffin	Cuboid	Paraffin-Plexi	3.00	5.290e-06
CAS25	1.0121	0.0024	UF4-Paraffin	Cuboid	Paraffin-Plexi	3.00	5.760e-06
CAS26	1.0128	0.0019	UF4-Paraffin	Cuboid	None	3.00	3.610e-06
CAS27	1.0111	0.0018	UF4-Paraffin	Cuboid	None	3.00	3.240e-06
CAS28	1.0079	0.0017	UF4-Paraffin	Cuboid	None	3.00	2.890e-06
CAS29X	1.0082	0.0016	UF4-Paraffin	Cuboid	Plexi, Poly	3.00	2.560e-06
CAS30	1.0109	0.0017	UF4-Paraffin	Cuboid	None	3.00	2.890e-06
CAS31	1.0130	0.0018	UF4-Paraffin	Cuboid	None	3.00	3.240e-06
CAS32	1.0096	0.0017	UF4-Paraffin	Cuboid	None	3.00	2.890e-06
CAS33	1.0006	0.0018	UO2F2	Cylinder	H2O,Cd,(SS)	4.98	3.240e-06
CAS34	0.9990	0.0017	UO2F2	Cylinder	H2O,(SS)	4.98	2.890e-06
CAS35	1.0007	0.0018	UO2F2	Sphere	None,(SS)	4.98	3.240e-06
CAS36	0.9992	0.0017	UO2F2	Cylinder	None,(SS)	4.98	2.890e-06

APPENDIX B
Summary of PC Scale-4.4/KENO-Va
Intermediate-Enriched Uranium Validation Calculations

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
VLD8RC1	1.0161	0.0023	UO2F2	8-Inch Dia. SS Cyl.	Water	30.30	5.290e-06
VLD8RC2	1.0128	0.0021	UO2F2	8-Inch Dia. SS Cyl.	Water	30.30	4.410e-06
VLD8RC3	1.0198	0.0023	UO2F2	8-Inch Dia. SS Cyl.	Water	30.30	5.290e-06
VLD8RC4	1.0098	0.0022	UO2F2	8-Inch Dia. SS Cyl.	Water	30.30	4.840e-06
VLD8RC5	1.0099	0.0020	UO2F2	8-Inch Dia. SS Cyl.	Water	30.30	4.000e-06
VLD8RC6	1.0135	0.0022	UO2F2	8-Inch Dia. SS Cyl.	Water	30.30	4.840e-06
VLD8RC7	1.0100	0.0023	UO2F2	8-Inch Dia. SS Cyl.	Water	30.30	5.290e-06
VLD12UC2	1.0074	0.0022	UO2F2	12-Inch Dia. SS Cyl.	None	30.30	4.840e-06
VLD12UC3	1.0064	0.0023	UO2F2	12-Inch Dia. SS Cyl.	None	30.30	5.290e-06
VLD12UC4	1.0088	0.0025	UO2F2	12-Inch Dia. SS Cyl.	None	30.30	6.250e-06
VLD12UC5	1.0060	0.0025	UO2F2	12-Inch Dia. SS Cyl.	None	30.30	6.250e-06
VLD12UC6	1.0031	0.0024	UO2F2	12-Inch Dia. SS Cyl.	None	30.30	5.760e-06
VLD12UC7	1.0085	0.0027	UO2F2	12-Inch Dia. SS Cyl.	None	30.30	7.290e-06
VLD12UC8	1.0068	0.0023	UO2F2	12-Inch Dia. SS Cyl.	None	30.30	5.290e-06
VLD12RC1	1.0020	0.0026	UO2F2	12-Inch Dia. SS Cyl.	Water	30.30	6.760e-06
VLD12RC2	1.0034	0.0024	UO2F2	12-Inch Dia. SS Cyl.	Water	30.30	5.760e-06
VLD12RC3	0.9973	0.0022	UO2F2	12-Inch Dia. SS Cyl.	Water	30.30	4.840e-06
VLD12RC4	1.0005	0.0025	UO2F2	12-Inch Dia. SS Cyl.	Water	30.30	6.250e-06
VLD12RC5	1.0045	0.0022	UO2F2	12-Inch Dia. SS Cyl.	Water	30.30	4.840e-06
VLD12RC6	1.0037	0.0025	UO2F2	12-Inch Dia. SS Cyl.	Water	30.30	6.250e-06
VLD12RC7	1.0033	0.0023	UO2F2	12-Inch Dia. SS Cyl.	Water	30.30	5.290e-06
VLD12RC8	1.0015	0.0021	UO2F2	12-Inch Dia. SS Cyl.	Water	30.30	4.410e-06
VLD12RC9	1.0046	0.0022	UO2F2	12-Inch Dia. SS Cyl.	Water	30.30	4.840e-06
VLD12R10	1.0065	0.0021	UO2F2	12-Inch Dia. SS Cyl.	Water	30.30	4.410e-06

APPENDIX B
Summary of PC Scale-4.4/KENO-Va
Intermediate-Enriched Uranium Validation Calculations
(continued)

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
VLD12R11	1.0068	0.0019	UO2F2	12-Inch Dia. SS Cyl.	Water	30.30	3.610e-06
VCD12RC1	1.0139	0.0023	UO2F2	12-Inch Dia. SS Cyl.	Water/Cadmium	30.30	5.290e-06
VCD12RC2	1.0069	0.0024	UO2F2	12-Inch Dia. SS Cyl.	Cadmium	30.30	5.760e-06
VCD12RC3	1.0207	0.0020	UO2F2	12-Inch Dia. SS Cyl.	Water/Cadmium	30.30	4.000e-06
VCD12RC4	1.0100	0.0020	UO2F2	12-Inch Dia. SS Cyl.	Cadmium	30.30	4.000e-06
VLD16UC1	1.0034	0.0022	UO2F2	16-Inch Dia. SS Cyl.	None	30.30	4.840e-06
VLD16UC2	1.0111	0.0021	UO2F2	16-Inch Dia. SS Cyl.	None	30.30	4.410e-06
VLD16UC3	1.0153	0.0023	UO2F2	16-Inch Dia. SS Cyl.	None	30.30	5.290e-06
VLD16UC4	1.0089	0.0022	UO2F2	16-Inch Dia. SS Cyl.	None	30.30	4.840e-06
VLD16UC5	1.0067	0.0018	UO2F2	16-Inch Dia. SS Cyl.	None	30.30	3.240e-06
VLD16UC6	1.0063	0.0019	UO2F2	16-Inch Dia. SS Cyl.	None	30.30	3.610e-06
VLD16UC7	1.0034	0.0020	UO2F2	16-Inch Dia. SS Cyl.	None	30.30	4.000e-06
VLD16RC1	1.0038	0.0021	UO2F2	16-Inch Dia. SS Cyl.	Water	30.30	4.410e-06
VLD16RC2	1.0067	0.0022	UO2F2	16-Inch Dia. SS Cyl.	Water	30.30	4.840e-06
VLD16RC3	1.0146	0.0024	UO2F2	16-Inch Dia. SS Cyl.	Water	30.30	5.760e-06
VLD16RC4	1.0101	0.0024	UO2F2	16-Inch Dia. SS Cyl.	Water	30.30	5.760e-06
VLD16RC5	1.0040	0.0023	UO2F2	16-Inch Dia. SS Cyl.	Water	30.30	5.290e-06
VLD16RC6	1.0046	0.0019	UO2F2	16-Inch Dia. SS Cyl.	Water	30.30	3.610e-06
VLD16RC7	1.0045	0.0020	UO2F2	16-Inch Dia. SS Cyl.	Water	30.30	4.000e-06
VLD16RC8	1.0032	0.0017	UO2F2	16-Inch Dia. SS Cyl.	Water	30.30	2.890e-06
VLD16RC9	1.0109	0.0021	UO2F2	16-Inch Cyl. w/ Dump Line	Water	30.30	4.410e-06
VLD16R10	1.0175	0.0024	UO2F2	16-Inch Cyl. w/ Dump Line	Water	30.30	5.760e-06

APPENDIX C
Summary of PC Scale-4.4/KENO-Va
High-Enriched Uranium Validation Calculations

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	$σ^2$
CAA01	1.0060	0.0016	UO2F2	Sphere	None	93.20	2.560e-06
CAA02	1.0013	0.0017	UO2F2	Sphere	None	93.20	2.890e-06
CAA03	1.0001	0.0015	UNH	Sphere	None	93.20	2.250e-06
CAA04	1.0057	0.0024	UO2F2	Sphere	Water	93.20	5.760e-06
CAA05	1.0026	0.0023	UO2F2	Sphere	Water	93.20	5.290e-06
CAA06	0.9998	0.0015	UO2F2	Sphere	Water	93.20	2.250e-06
CAA07	1.0075	0.0023	UO2F2	Sphere	Water	93.20	5.290e-06
CAA09	1.0089	0.0026	UO2F2	Sphere	None	93.20	6.760e-06
CAA12	1.0100	0.0027	UNH	Cylinder	None	93.20	7.290e-06
CAA13	1.0118	0.0025	UNH	Cylinder	None	93.20	6.250e-06
CAA14	1.0043	0.0024	UNH	Cylinder	None	93.20	5.760e-06
CAA15	1.0072	0.0024	UNH	Cylinder	None	93.20	5.760e-06
CAA16	1.0037	0.0026	UNH	Cylinder	None	93.20	6.760e-06
CAA17	1.0108	0.0026	UNH	Cylinder	Concrete	93.20	6.760e-06
CAA18	1.0140	0.0024	UNH	Cylinder	Concrete	93.20	5.760e-06
CAA19	1.0102	0.0024	UNH	Cylinder	Concrete	93.20	5.760e-06
CAA20	1.0057	0.0024	UNH	Cylinder	Concrete	93.20	5.760e-06
CAA21	1.0133	0.0021	UNH	Cylinder	Concrete	93.20	4.410e-06
CAA22	1.0029	0.0024	UNH	Cylinder	Concrete	93.20	5.760e-06
CAA23	1.0114	0.0024	UNH	Cylinder	Plexiglass	93.20	5.760e-06
CAA24	1.0103	0.0025	UNH	Cylinder	Plexiglass	93.20	6.250e-06
CAA25	1.0040	0.0026	UNH	Cylinder	Plexiglass	93.20	6.760e-06
CAA26	1.0059	0.0023	UNH	Cylinder	Plexiglass	93.20	5.290e-06
CAA27	1.0113	0.0022	UNH	Cylinder	Plexiglass	93.20	4.840e-06

APPENDIX C
Summary of PC Scale-4.4/KENO-Va
High-Enriched Uranium Validation Calculations
(continued)

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
CAA28	1.0061	0.0023	UNH	Cylinder	Plexiglass	93.20	5.290e-06
CAA29	1.0040	0.0020	UNH	Cylinder	Concrete	93.20	4.000e-06
CAA30	1.0018	0.0024	UNH	Cylinder	Concrete	93.20	5.760e-06
CAA31	1.0125	0.0021	UNH	Cylinder	Concrete	93.20	4.410e-06
CAA32	1.0118	0.0020	UNH	Cylinder	Concrete	93.20	4.000e-06
CAA33	1.0051	0.0022	UNH	Cylinder	Concrete	93.20	4.840e-06
CAA34	1.0044	0.0028	UNH	Cylinder	Concrete	93.20	7.840e-06
CAA35	1.0097	0.0021	UNH	Cylinder	Concrete	93.20	4.410e-06
CAA36	1.0070	0.0022	UNH	Cylinder	Concrete	93.20	4.840e-06
CAA37	0.9981	0.0020	UNH	Cylinder	Plexiglass	93.20	4.000e-06
CAA38	0.9938	0.0025	UNH	Cylinder	Plexiglass	93.20	6.250e-06
CAA39	1.0017	0.0022	UNH	Cylinder	Plexiglass	93.20	4.840e-06
CAA40	0.9970	0.0025	UNH	Cylinder	Plexiglass	93.20	6.250e-06
CAA41	1.0028	0.0019	UNH	Cylinder	Plexiglass	93.20	3.610e-06
CAA42	1.0088	0.0026	UNH	Cylinder	Plexiglass	93.20	6.760e-06
CAA43	1.0032	0.0022	UNH	Cylinder	Plexiglass	93.20	4.840e-06
CAS01	1.0026	0.0015	Metal	Sphere	None	93.80	2.250e-06
CAS02	1.0029	0.0018	Metal	Sphere	Water	97.67	3.240e-06
CAS03	1.0116	0.0025	UNH	Cylinder	None	93.20	6.250e-06
CAS04	1.0028	0.0017	Alloy	Cylinder	None	93.20	2.890e-06
CAS08	0.9788	0.0017	Metal	Cylinder	Graphite	93.20	2.890e-06
CAS09	1.0092	0.0019	Metal	Cuboid	Natural U	94.00	3.610e-06
CAS10	1.0154	0.0017	Metal	Hemisphere	Oil	93.10	2.890e-06
CAS11	1.0064	0.0020	Metal	Hemisphere	Oil	93.10	4.000e-06

APPENDIX C
Summary of PC Scale-4.4/KENO-Va
High-Enriched Uranium Validation Calculations
(continued)

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
CAS12	1.0005	0.0019	Metal	Cylinder	None	93.20	3.610e-06
CAS15	1.0028	0.0018	Metal	Cylinder	Polyethylene	93.20	3.240e-06
CAS22	1.0059	0.0016	Metal	Cylinder	None	93.20	2.560e-06
CAS23	0.9974	0.0018	Metal	Mixed	None	93.20	3.240e-06
CAS24	0.9943	0.0017	Metal	Cylinder	None	93.20	2.890e-06
CAS25	1.0029	0.0017	Metal	Cylinder	None	93.20	2.890e-06
CAS26	1.0032	0.0018	Metal	Cylinder	Paraffin	93.20	3.240e-06
CAS27	1.0051	0.0018	Metal	Cylinder	Paraffin	93.20	3.240e-06
CAS28	1.0082	0.0018	Metal	Cylinder	Plexiglass	93.20	3.240e-06
CAS60	0.9979	0.0023	UNH	Cylinder	Room	92.60	5.290e-06
CAS61	1.0110	0.0022	UNH	Cylinder	Room	92.60	4.840e-06
CAS62	1.0002	0.0023	UNH	Cylinder	Room	92.60	5.290e-06
CAS63	0.9989	0.0027	UNH	Cylinder	Room	92.60	7.290e-06
CAS64	0.9992	0.0022	UNH	Cylinder	Room	92.60	4.840e-06
CAS65	1.0070	0.0022	UNH	Cylinder	Room	92.60	4.840e-06
CAS66	1.0104	0.0026	UNH	Cylinder	Paraffin/Plexi	92.60	6.760e-06
CAS67	1.0176	0.0027	UNH	Cylinder	Paraffin/Plexi	92.60	7.290e-06
CAS68	1.0145	0.0026	UNH	Cylinder	Paraffin/Plexi	92.60	6.760e-06
CAS69	1.0183	0.0024	UNH	Cylinder	Paraffin/Plexi	92.60	5.760e-06
CAS70	1.0213	0.0023	UNH	Cylinder	Paraffin/Plexi	92.60	5.290e-06
CAS71	1.0288	0.0024	UNH	Cylinder	Paraffin/Plexi	92.60	5.760e-06
CAS72	1.0027	0.0022	UNH	Cylinder	Plexiglass	92.60	4.840e-06
CAS73	1.0124	0.0023	UNH	Cylinder	Paraffin/Plexi	92.60	5.290e-06
CAS75	1.0288	0.0023	UNH	Cylinder	Paraffin/Plexi	92.60	5.290e-06

APPENDIX C
Summary of PC Scale-4.4/KENO-Va
High-Enriched Uranium Validation Calculations
(continued)

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
CAS79	1.0131	0.0021	UNH	Cylinder	Paraffin/Plexi	92.60	4.410e-06
CAS80	1.0193	0.0024	UNH	Cylinder	Paraffin/Plexi	92.60	5.760e-06
CAS81	1.0201	0.0024	UNH	Cylinder	Paraffin/Plexi	92.60	5.760e-06
CAS82	1.0156	0.0024	UNH	Cylinder	Paraffin/Plexi	92.60	5.760e-06
CAS83	1.0163	0.0022	UNH	Cylinder	Paraffin/Plexi	92.60	4.840e-06
CAS84	1.0174	0.0024	UNH	Cylinder	Paraffin/Plexi	92.60	5.760e-06
CAS85	1.0102	0.0023	UNH	Cylinder	Plexiglass	92.60	5.290e-06
CAS86	1.0118	0.0021	UNH	Cylinder	Paraffin/Plexi	92.60	4.410e-06
CAS87	1.0170	0.0023	UNH	Cylinder	Paraffin/Plexi	92.60	5.290e-06
CAS88	1.0170	0.0023	UNH	Cylinder	Paraffin/Plexi	92.60	5.290e-06
CAS89	1.0235	0.0023	UNH	Cylinder	Paraffin/Plexi	92.60	5.290e-06
CAS90	1.0013	0.0026	UNH	Cylinder	Room	92.60	6.760e-06
CAS91	1.0053	0.0022	UNH	Cylinder	Room	92.60	4.840e-06
CAM30	1.0038	0.0022	UO2F2	Slab	Room	93.20	4.840e-06
CAM31	0.9940	0.0023	UO2F2	Slab	Water	93.20	5.290e-06
CAM32	0.9912	0.0025	UO2F2	Slab	Room	93.20	6.250e-06
CAM33	0.9990	0.0026	UO2F2	Slab	Water	93.20	6.760e-06
CAM34	0.9907	0.0022	UO2F2	Slab	Room	93.20	4.840e-06
CAM35	0.9934	0.0023	UO2F2	Slab	Water	93.20	5.290e-06
CAM36	0.9967	0.0027	UO2F2	Slab	Room	93.20	7.290e-06
CAM37	1.0015	0.0020	UO2F2	Slab	Water	93.20	4.000e-06
CAM38	0.9880	0.0021	UO2F2	Slab	Room	93.20	4.410e-06
CAM39	0.9994	0.0020	UO2F2	Slab	Water	93.20	4.000e-06
CAM40	0.9895	0.0027	UO2F2	Slab	Room	93.20	7.290e-06
CAM41	0.9847	0.0026	UO2F2	Slab	Room	93.20	6.760e-06

APPENDIX C
Summary of PC Scale-4.4/KENO-Va
High-Enriched Uranium Validation Calculations
(continued)

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
CAM38	0.9880	0.0021	UO2F2	Slab	Room	93.20	4.410e-06
CAM39	0.9994	0.0020	UO2F2	Slab	Water	93.20	4.000e-06
CAM40	0.9895	0.0027	UO2F2	Slab	Room	93.20	7.290e-06
CAM41	0.9847	0.0026	UO2F2	Slab	Room	93.20	6.760e-06
CAM42	0.9870	0.0023	UO2F2	Slab	Room	93.20	5.290e-06
CAM43	0.9804	0.0025	UO2F2	Slab	Room	93.20	6.250e-06
CAM44	0.9816	0.0022	UO2F2	Slab	Room	93.20	4.840e-06
CAM45	0.9916	0.0025	UO2F2	Slab	Room	93.20	6.250e-06
CAM46	0.9801	0.0025	UO2F2	Slab	Room	93.20	6.250e-06
CAM47	0.9873	0.0024	UO2F2	Slab	Room	93.20	5.760e-06
CAM48	0.9850	0.0021	UO2F2	Slab	Room	93.20	4.410e-06
CAM49	0.9919	0.0024	UO2F2	Slab	Room	93.20	5.760e-06
CAM50	0.9930	0.0023	UO2F2	Slab	Room	93.20	5.290e-06
CAM51	0.9953	0.0025	UO2F2	Slab	Room	93.20	6.250e-06
CAM52	0.9946	0.0019	UO2F2	Slab	Room	93.20	3.610e-06
CAM53	0.9919	0.0023	UO2F2	Slab	Room	93.20	5.290e-06
CAM54	0.9909	0.0024	UO2F2	Slab	Room	93.20	5.760e-06
CAM55	0.9901	0.0025	UO2F2	Slab	Room	93.20	6.250e-06
CAM56	0.9889	0.0021	UO2F2	Slab	Room	93.20	4.410e-06
CAM57	0.9922	0.0022	UO2F2	Slab	Room	93.20	4.840e-06
CAM58	0.9909	0.0020	UO2F2	Slab	Room	93.20	4.000e-06
CAM59	0.9856	0.0022	UO2F2	Slab	Room	93.20	4.840e-06
CAE02	0.9999	0.0016	UNH	Sphere	None	93.20	2.560e-06
CAE03	0.9952	0.0017	UNH	Sphere	None	93.20	2.890e-06

APPENDIX C
Summary of PC Scale-4.4/KENO-Va High-Enriched Uranium Validation Calculations (continued)

Run ID	K-eff	σ	Material	Geometry	Reflector	% Enrich	σ^2
CAE04	0.9961	0.0015	UNH	Sphere	None	93.20	2.250e-06
CAE10	0.9958	0.0011	UNH	Sphere	None	93.20	1.210e-06
CAE12	0.9963	0.0014	UNH	Cylinder	None	93.20	1.960e-06
CAE13	0.9933	0.0013	UNH	Cylinder	None	93.20	1.690e-06
CAE14	0.9990	0.0009	UNH	Cylinder	None	93.20	8.100e-07
CAE15	0.9987	0.0011	UNH	Cylinder	None	93.20	1.210e-06
CAE16	0.9964	0.0010	UNH	Cylinder	None	93.20	1.000e-06
CAE21	0.9949	0.0010	UNH	Cylinder	None	93.20	1.000e-06
CAE22	0.9968	0.0009	UNH	Cylinder	None	93.20	8.100e-07
CAE23	0.9966	0.0009	UNH	Cylinder	None	93.20	8.100e-07

1) k_{exp} ^{1} 1
2) Graphite moderated
3) k_{exp} ^{1} 1

APPENDIX D
Sample Statistical Analysis

Find a single value above which it is predicted with 95% confidence that 99.9% of the critical values will lie (M. G. Natrella, Reference 9, page 2-14):

$P = 0.999$

$\gamma = 0.95$

$\bar{x} \equiv$ Arithmetic mean of the benchmark cases = 1.0025

$n \equiv$ Sample size = 290

$s \equiv$ Population Standard Deviation = 0.0104

$T \equiv$ Factor for one-sided tolerance limit (Reference 10, Page 50)

Then, for $T(n,\gamma,P)$ the table value is:

$T(\,290, 0.95, 0.999\,) = 3.3382$

Upper Safety Limit $\equiv$ USL $= X_L = \bar{x} - T_{(n,\gamma,P)}s = 1.0024 - (3.3382)(0.0096) = 0.9704$

Bias* $\equiv k_{calculated} - k_{experimental} = 1.0025 - 1.0000 = (+)0.0025$

*Note: The value of "X_L" also contains the bias (i.e., the bias is included in the expression "$\bar{x} - T_{n,\gamma,P)}s$").

References and Data Available:

1. Scale 4.4 Manual
2. PSR-6
3. PSR-18
4. NCSE-001
5. NCSE-002
6. Validation Reports in BUF Calc files

Design Criteria: See WVDP-162

Assumptions: See individual Cases and Attachments

Prepared by:	C Alvin Sweet Signature	3-17-04 Date
Checked by:	[illegible] Signature	3/17/04 Date
Approved by:	Joseph C Wolniewicz Signature	05/11/04 Date

URS

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Calculation Cover Page

Job No: **39399976 / 06354** Calculation No: **BUF-04-034/Rev. 0** Date: **March 1, 2004**

**VALIDATION OF THE SCALE-PC (VERSION 4.4a)
COMPUTER CODE PACKAGE FOR MIXED URANIUM/PLUTONIUM SYSTEMS**

Problem Statement and Calculation Objectives: This calculation covers the validation of the SCALE- PC (Version 4.4a) computer code package for mixed Uranium/Plutonium systems at West Valley Demonstration Plant.

(IBM P4-3060 Personal Computer - Serial No. 412-56-6368-1A)

TABLE OF CONTENTS

1.0 INTRODUCTION

The SCALE-PC (Version 4.4a) computer code package was validated for use on the URS Personal Computer (Serial No. 412-56-6368-1A). These validation calculations were performed for mixed uranium/plutonium systems using the 27-group cross section library. The systems modeled contained MOX-metal rods in H_2O solution, MOX-metal rods in PuNitrate solution, Delta Phase Pu/HEU metal, Pu/HEU metal, and Pu/U Nitrate solution. The various systems were also modeled using different materials, geometries, arrays, and reflectors.

The Uranium systems analyzed for this report range in enrichments from 0.72 to 93.28 weight percent U-235. The Plutonium systems analyzed for this report range in enrichments from 71.80 to 97.56 weight percent Pu-239.

When performing the validation, the American National Standards Institute guidance in ANSI/ANS-8.1[1] was considered. The standard requires that calculational methods used for criticality safety analyses are validated and that any bias be determined by correlating the results of critical experiments with calculations. The methods were the same as those used in the validation performed at Oak Ridge[2].

2.0 DESCRIPTION OF THE SCALE-4.4 SYSTEM

SCALE-4.4a is a modular code system for performing Standardized Computer Analyses for Licensing Evaluations. This system consists of modules to prepare cross-section sets and modules to perform both Monte-Carlo and discrete ordinates neutronics calculations using these cross-section sets. The calculations performed in this validation involved the use of the Monte-Carlo code KENO-Va, developed at the Oak Ridge National Laboratory (ORNL)[3].

A set of Criticality Safety Analysis Sequence (CSAS) control modules is used in the SCALE-4.4a system to call the various functional modules. Because this validation was performed for Monte-Carlo calculations, only the control and functional modules that pertain to the Monte-Carlo calculations are described in this section. For a complete description of the SCALE-4.4 and KENO-Va and KENO-VI system and mathematical methods used therein, refer to the SCALE-4.4 Manual[4].

SCALE.EXE is a frozen version of a system of nuclear criticality safety codes available in the SCALE-4.4 PC package (RSIC #C00545/MNYCP00). The sequence being validated is the CSAS25 sequence documented in the SCALE-4.4 manual. This sequence uses control module CSAS.EXE and program modules O0O008.EXE (BONAMI-2), O0O002.EXE (NITAWL), and O0O009.EXE (KENO-Va). The 27-group ENDF/B-IV cross-section master library, stored in data set FT82F001, was used for all calculations.

2.1 CSAS25 and CSAS4

The CSAS25 and CSAS4 control modules call the functional modules in the order BONAMI (Bondarenko AMPX Interpolator), NITAWL (Nordheim Integral Treatment AMPX Working Library), and KENO-Va. The only difference between the CSAS25 module and the CSAS4 module is that the CSAS4 module allows the user to perform dimensional searches for various geometries and array pitches for given k-effective values. Because the same cross sections (prepared by BONAMI and NITAWL) are used for each KENO-Va run, validations performed using the CSAS25 control module will apply to calculations performed using the CSAS4 module.

2.2 BONAMI

The primary purpose of the BONAMI functional module is to select the required cross-sections and to create a smaller master cross-section library to be processed by NITAWL. This module also performs resonance self-shielding calculations for nuclides that have Bondarenko data associated with their cross sections.

2.3 NITAWL

The NITAWL functional module treats the resonance region cross sections for resonance absorbers. This treatment is based upon the Nordheim Integral Transform method. The user has the option of treating the resonance parameters in the manner most appropriate for the problem detail. The three methods used are as follows (with description):

1. **INFHOMMEDIUM** This option treats the material as an infinite homogeneous mixture.
2. **LATTICECELL** This option treats a multiple repeated cell for resonance self-shielding correction.
3. **MULTIREGION** This option treats a single cell for resonance self-shielding correction.

2.4 KENO

The KENO code uses the integral form of the neutron transport equation to solve for an eigenvalue k, which is the multiplication constant or k-effective (k_{eff}). KENO uses a Monte-Carlo technique to determine neutron mean free path, absorption, fission, scattering, and leakage. The k-effective value indicates the degree to which the system being analyzed is subcritical, critical, or supercritical.

The KENO-Va code is a substantial revision of the KENO-IV code. The KENO-Va code allows for holes, array of arrays, enhanced plotting capabilities, and variable chords for hemi-cylinders and hemispheres. The primary purpose of the KENO-Va code is to calculate the k-effective value. However, the code also calculates fissions, fission densities, neutron fluxes, neutron lifetimes, and energy and region dependent absorptions.

The KENO-VI code is a substantial revision of the KENO-Va code. KENO-VI/(CSAS26) would be validated in a separate document.

2.5 27-GROUP CROSS-SECTION LIBRARY FROM ENDF/B-IV

The 27-Group ENDF/B-IV cross section library was created in 1981 from the 218 Group ENDF/B-IV cross section library set. Before that time, the 16 Group Hansen-Roach, Knight-Modified cross section set was most often used. The 27-group set is considered an improvement because more thermal groups are available and because upscatter is included.

2.6 44-GROUP and 238-GROUP CROSS-SECTION LIBRARIES FROM ENDF/B-V

The 123GROUP and 218GROUP cross-section-library keywords were replaced with 44GROUP and 238GROUP. The former libraries, which were the least used of the standard SCALE libraries, were removed as defaults so the new ENDF/B-V libraries, which give more accurate results, could be accessed directly via keyword input.

3.0 DISCUSSION OF RESULTS

A total of 76 benchmark experiments[5] from the Nuclear Energy Agency (NEA) were used to validate the SCALE-4.4 CSAS4 and CSAS25 modules.

Table 1 correlates the new case number with the original directory and case number.

TABLE 1. NEW CASE NUMBERS

DIRECTORY	CASENO	NEW CASENO
MIXMF.011	ZPPR-21B	MF11001
MIXMF.011	ZPPR-21C	MF11002
MIXMF.011	ZPPR-21D	MF11003
MIXMF.011	ZPPR-21E	MF11004
MIXMCT.001	MMCT.106	MCT01001
MIXMCT.001	MMCT.107	MCT01002
MIXMCT.001	MMCT.109	MCT01003
MIXMCT.001	MMCT.110	MCT01004
MIXMCT.001	MMCT.111	MCT01005
MIXMCT.001	MMCT.112	MCT01006
MIXMCT.001	MMCT.113	MCT01007
MIXMCT.001	MMCT.114	MCT01008
MIXMCT.001	MMCT.115	MCT01009
MIXMF.001	CASE_1	MF01001
MIXMF.002	CASE_1	MF02001
MIXMF.002	CASE_2	MF02002
MIXMF.002	CASE_3	MF02003
MIXCT.008	CASE_1	MCT08001
MIXCT.008	CASE_2	MCT08002
MIXCT.008	CASE_3	MCT08003
MIXCT.008	CASE_4	MCT08004
MIXCT.008	CASE_5	MCT08005
MIXCT.008	CASE_6	MCT08006
MIXCT.008	CASE_AL	MCT08007
MIXCT.008	CASE_ALC	MCT08008
MIXCT.008	CASE_B1	MCT08009
MIXCT.008	CASE_B1C	MCT08010
MIXCT.008	CASE_B2	MCT08011
MIXCT.008	CASE_B2C	MCT08012
MIXCT.008	CASE_B3	MCT08013
MIXCT.008	CASE_B3C	MCT08014
MIXCT.008	CASE_B4	MCT08015
MIXCT.008	CASE_B4C	MCT08016
MIXCT.008	CASE_CD	MCT08017
MIXCT.008	CASE_H1	MCT08018
MIXCT.008	CASE_H1C	MCT08019
MIXCT.008	CASE_H2	MCT08020
MIXCT.008	CASE_H2C	MCT08021
MIXCT.008	CASE_H3	MCT08022
MIXCT.008	CASE_H3C	MCT08023
MIXCT.008	CASE_H4	MCT08024
MIXCT.008	CASE_H4C	MCT08025
MIXCT.008	CASE_H5	MCT08026
MIXCT.008	CASE_H5C	MCT08027
MIXST.001	A100.INP	MST01001
MIXST.001	A108.INP	MST01002
MIXST.001	A87.INP	MST01003
MIXST.001	A87S.INP	MST01004
MIXST.001	A91.INP	MST01005
MIXST.001	A92.INP	MST01006

TABLE 1. NEW CASE NUMBERS (continued)

MIXST.001	A93.INP	MST01007
MIXST.001	A94.INP	MST01008

```
MIXST.001  A95.INP     MST01009
MIXST.001  A96.INP     MST01010
MIXST.001  A97.INP     MST01011
MIXST.001  A98.INP     MST01012
MIXST.001  A99.INP     MST01013
MIXST.002  B11058.INP  MST02001
MIXST.002  B11059.INP  MST02002
MIXST.002  B63061.INP  MST02003
MIXST.004  D15677.INP  MST04001
MIXST.004  D16678.INP  MST04002
MIXST.004  D19669.INP  MST04003
MIXST.004  D20670.INP  MST04004
MIXST.004  D25665.INP  MST04005
MIXST.004  D26666.INP  MST04006
MIXST.004  F17583.INP  MST04007
MIXST.004  F18568.INP  MST04008
MIXST.004  F27567.INP  MST04009
MIXST.005  C13175.INP  MST05001
MIXST.005  C22B74.INP  MST05002
MIXST.005  C23B63.INP  MST05003
MIXST.005  D14176.INP  MST05004
MIXST.005  D21171.INP  MST05005
MIXST.005  D21172.INP  MST05006
MIXST.005  D24164.INP  MST05007
```

The following had minor errors easily recognized and corrected:

```
MF01001  Added the word GLOBAL.
MF02001  Added the word GLOBAL.
MF02002  Added the word GLOBAL.
MF02003  Added the word GLOBAL.
MCT01001 Decimal point in wrong place.
MCT01002 Decimal point in wrong place.
MCT01003 Decimal point in wrong place.
MCT01007 Decimal points in wrong place.
MCT01008 Decimal point in wrong place.
MCT01009 Decimal point in wrong place.
```

The following had to have the number 2.3366 changed to 2.336599 in eight places:

```
MST04007
MST04008
MST04009
```

These thirteen files were recovered and used in the KENOmix group.

The experimental k values for various validation experiments were not unity and therefore the calculated k-effective values should be normalized to the experimental value using the formula $k_{report} = k_{calc}/k_{exp}$, where the subscripts "report," "calc," and "exp" refer to the k values reported, calculated, and experimental, respectively.

The calculations performed for the URS validation were made using no less than 103 generations with no less than 300 neutrons per generation. According to generally accepted practice, the k-effective values for at least the first three generations were not included in the mean k-effective calculation because the poor spatial distribution of the neutrons would tend to bias the results. The results of the calculations are given in Appendix A. Appendix B gives a sample statistical analysis. The data was also determined to be normally distributed.

The statistical analysis procedure consisted of determining a mean and a standard deviation for the set of k-effective values being analyzed. A one-sided lower tolerance limit was then determined such that one can predict with 95% confidence that 99.9% of the k-effective values for critical systems will lie above this limit. One can then be confident that a k-effective below this limit represents a subcritical condition. For this application, the lower tolerance limit was designated the Upper Safety Limit (USL). The statistical method used is explained in Reference 6 and the factors for the one-sided tolerance limits (tolerance limit factors) are given in Reference 7. Refer to Appendix B for more details regarding the USL calculation. Refer to Appendix D in BUF-04-032 for more details regarding the One-Sided Tolerance Interval calculation. This technique is similar to the technique proposed by H. R. Dyer[11], except that the data was pooled rather than being used with a correlating parameter (e.g., moderating ratio, average energy group causing fission, or ratio of total fissions to thermal fissions). The bias is defined as the difference between the average and the true value or, as in the case of this validation, the difference between the arithmetic mean of calculated k-effective values and the experimental k-effective value (i.e., k_{calc} minus k_{exp}). It should also be noted that the value of the USL contains the bias, for example, the bias is included in the expression

"$\bar{X} - T_{(n,\gamma,P)}s$".

Statistical analysis was performed giving these results:

TABLE OF STATISTICAL ANALYSES						
Grouping	No. of Cases	Mean k-eff	Standard Deviation	Bias	Tolerance Limit Factor[10]	USL
Entire Set	76	1.0028	0.0056	(+)0.0028	3.6105	0.9827

For safety analysis purposes, a calculated k-effective plus two standard deviations must lie below the USL (i.e., $k_{eff} + 2\sigma <$ USL). This statistical method for code validation allows the USL to be established such that there is a high degree of confidence that a calculated result which satisfies the acceptance criteria is indeed subcritical.

Although a margin of subcriticality is not specifically determined by the technique, a margin can be defined as the difference between the one-sided 95% lower confidence limit and the USL (also called the 95/99.9 lower tolerance limit)[11,12]. The one-sided 95% lower confidence limit is defined by the equation

$$\bar{X} - T_p s$$

where T_p is read from a table of the inverse normal probability distribution. The value of T_p varies with the number of samples[9]. Refer to the following table for calculated margins of subcriticality:

TABLE OF STATISTICAL ANALYSES				
Grouping	95% Lower Confidence Limit	Tolerance Limit Factor	USL	Margin of Subcriticality
Entire Set	0.9918	1.970	0.9827	0.0091

95% Lower Confidence Limit ≡ LCL = $\bar{X} - T_{(n,\gamma,P)}s$ = 1.0028 - (1.970)(0.0056) = 0.9827
Theoretical Margin of Subcriticality = 95% LCL - USL = .9918 - .9827 = 0.0091

According to generally accepted practice throughout the criticality safety community, the maximum allowable calculated k-effective plus two standard deviations shall be less than or equal to 0.95 (i.e., $k_{eff} + 2\sigma \leq 0.95$). Since the bias is included in the USL, and since all USLs are greater than 0.95, the real margin of subcriticality is the difference between the one-sided lower 95% confidence limit and 0.95. Refer to the following table for the recalculated margins of subcriticality:

MARGINS OF SUBCRITICALITY		
Grouping	95% Lower Confidence Limit	Margin of Subcriticality
Entire Set	0.9918	0.0418

According to generally accepted practice, the margin of subcriticality should be at least 0.02[13]. When recalculated, the margin of subcriticality for the entire grouping is 0.0418.

For materials other than those modeled in these calculations and for other enrichments, a (-)0.01 Δk uncertainty is applied to the USL calculated for the entire data set. Δk is all other unknown uncertainties. This results in a lower USL of **0.9827 - 0.010028 = 0.9727**. Since the bias is included in the USL, and since the USL is equal to 0.9727, the maximum allowable calculated k-effective plus two standard deviations for these materials shall be less than or equal to 0.95 (i.e., $k_{eff} + 2\sigma \leq 0.95$).

4.0 CONCLUSIONS

The SCALE-PC (Version 4.4) computer code package accurately calculates a broad range of critical experiments and can be used with great confidence for the design and criticality safety analysis of uranium/plutonium-bearing systems.

This validation meets the criteria for "validation of a calculational method" specified in Reference 1 (Section 4.3) as follows:

Types of systems that can be modeled:

Systems enriched in the U-235 isotope and the Pu-239 isotope
All chemical forms of the mixed uranium/plutonium compounds
All physical forms of the mixed uranium/plutonium compounds
Moderated and unmoderated systems
Single units and arrays
All geometries

Range of parameters which may be treated:

Enrichment: Any (wt.% U-235 and wt% Pu-239)
Moderators: Any
Degrees of Moderation: All
Reflectors: Any
Concentration/Density: U Metal at theoretical density to infinitely dilute solutions

Bias in the results produced by this method:

The bias in this category is (+)0.0028 (i.e., $k_{calculated}$ minus $k_{experimental}$).

Margin of Subcriticality:

The margin of subcriticality for any case in this category is 0.0418.

Additionally, since all USLs are greater than or equal to 0.9500, and since the bias is included in the USL, a system can be considered acceptably subcritical if a converged k-effective value plus two standard deviations is less than or equal to 0.95 (i.e., $k_{eff} + 2\sigma \leq 0.95$).

Note: Although this validation utilized values of NPG and GEN $\geq$the default values of NPG=300 and GEN=103 (resulting in tracking 30,000 neutron histories after skipping the first three generations), increasing the number of neutrons and/or the number of generations (for a calculation) does not violate the basis of acceptable subcriticality as documented in this validation report (i.e., $k_{eff} + 2\sigma \leq 0.95$). While tracking more neutron histories will permit better convergence of the calculations, it also tends to lower the standard deviation of the calculation. However, as stated previously, this does not violate the basis of acceptable subcriticality.

5.0 REFERENCES

1) American National Standard, ANSI/ANS-8.1, Section 4.3, American Nuclear Society, 1983.

2) W. C. Jordan, N. F. Landers, L. M. Petrie, Validation of KENO-Va, Comparison With Critical Experiments, ORNL/CSD/TM-238, December 1986.

3) Radiation Shielding Information Center, C00545/MNYCP00, Oak Ridge National Laboratory, March 2000.

4) L. M. Petrie, N. F. Landers, KENO Va: An Improved Monte Carlo Program with Supergrouping, NUREG/CR-0200, Oak Ridge National Laboratory, March 2000.

5) Nuclear Energy Agency, Volumes I through VII, International Handbook of Evaluated Criticality Safety Benchmark Experiments, October 1992.

6) M. G. Natrella, Experimental Statistics, National Bureau of Standards Handbook 91, National Institute of Standards and Technology, August 1963.

7) D. B. Owen, Factors for One-Sided Tolerance Limits and for Variable Sampling Plans, SCR-607, Sandia Corporation Monograph, March 1963.

8) H. R. Dyer, W. C. Jordan, V. R. Cain, "A Technique for Code Validation for Criticality Safety Calculations," Transactions of the American Nuclear Society, 63, 238, (June 1991).

9) D. B. Owen, Handbook of Statistical Tables, Addison-Wesley, Page 12, 1962.

APPENDIX A
Summary of PC SCALE-4.4/KENO-Va
Mixed Uranium/Plutonium Validation Calculations

Run ID	K-eff	σ	Material	Geometry	Reflector	% Pu Enrich	% U Enrich	σ^2
MCT08001	0.9940	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08002	0.9978	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08003	1.0000	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08004	1.0041	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08005	1.0061	0.0002	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	4.000e-08
MCT08006	1.0054	0.0002	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	4.000e-08
MCT08007	1.0008	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08008	0.9973	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08009	0.9972	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08010	0.9968	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08011	0.9977	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08012	0.9976	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08013	0.9971	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08014	0.9977	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08015	0.9969	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08016	0.9967	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08017	0.9953	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08018	0.9958	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08019	0.9959	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08020	0.9958	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08021	0.9969	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08022	0.9965	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08023	0.9975	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08024	0.9964	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08025	0.9976	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08026	0.9960	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08
MCT08027	0.9966	0.0003	MOX Metal Rods in H2O	Tri. Pitch Array	H2O	71.80	0.72	9.000e-08

APPENDIX A
Summary of PC SCALE-4.4/KENO-Va
Mixed Uranium/Plutonium Validation Calculations
(continued)

Run ID	K-eff	σ	Material	Geometry	Reflector	% Pu Enrich	% U Enrich	σ^2
MCT01001	1.0017	0.0006	MOX Rods in PuNitrateSoln	Sq. Pitch Array	H2O	87.22	0.72	3.600e-07
MCT01002	1.0035	0.0006	MOX Rods in PuNitrateSoln	Sq. Pitch Array	H2O	87.22	0.72	3.600e-07
MCT01003	1.0038	0.0005	MOX Rods in PuNitrateSoln	Sq. Pitch Array	H2O	87.22	0.72	2.500e-07
MCT01004	1.0008	0.0005	MOX Rods in PuNitrateSoln	Sq. Pitch Array	H2O	87.22	0.72	2.500e-07
MCT01005	1.0060	0.0006	MOX Rods in PuNitrateSoln	Sq. Pitch Array	H2O	87.22	0.72	3.600e-07
MCT01006	1.0048	0.0006	MOX Rods in PuNitrateSoln	Sq. Pitch Array	H2O	87.22	0.72	3.600e-07
MCT01007	1.0020	0.0005	MOX Rods in PuNitrateSoln	Sq. Pitch Array	H2O	87.22	0.72	5.000e-04
MCT01008	1.0000	0.0005	MOX Rods in PuNitrateSoln	Sq. Pitch Array	H2O	87.22	0.72	2.500e-07
MCT01009	0.9981	0.0005	MOX Rods in PuNitrateSoln	Sq. Pitch Array	H2O	87.22	0.72	2.500e-07
MF01001	0.9916	0.0025	Delta Phase Pu/HEU Metal	Sphere	Bare	94.79	93.28	6.250e-06
MF02001	1.0070	0.0014	Pu/HEU Metal	Sphere	Bare	97.56	46.67	1.960e-06
MF02002	1.0038	0.0015	Pu/HEU Metal	Sphere	Bare	94.97	46.67	2.250e-06
MF02003	1.0095	0.0012	Pu/HEU Metal	Sphere	Bare	83.96	46.67	1.440e-06
MF11001	1.0068	0.0003	MOX Metal Rods	Cyl Array	Graphite	93.56	18.44	9.000e-08
MF11002	1.0119	0.0003	MOX Metal Rods	Cyl Array	Graphite	92.93	39.49	9.000e-08
MF11003	1.0156	0.0002	MOX Metal Rods	Cyl Array	Graphite	91.65	46.11	4.000e-08
MF11004	1.0154	0.0002	MOX Metal Rods	Cyl Array	Graphite	87.55	55.44	4.000e-08
MST01001	1.0141	0.0016	Pu/U Nitrate Soln	Cyl Array	H2O	91.17	0.71	2.560e-06
MST01002	1.0043	0.0017	Pu/U Nitrate Soln	Cyl Array	H2O	91.14	0.71	2.890e-06
MST01003	1.0035	0.0015	Pu/U Nitrate Soln	Cyl Array	H2O	91.18	0.70	2.250e-06
MST01004	1.0038	0.0018	Pu/U Nitrate Soln	Cyl Array	H2O	91.18	0.70	3.240e-06
MST01005	0.9988	0.0018	Pu/U Nitrate Soln	Cyl Array	H2O	91.16	0.71	3.240e-06
MST01006	1.0031	0.0015	Pu/U Nitrate Soln	Cyl Array	H2O	91.18	0.71	2.250e-06
MST01007	1.0064	0.0018	Pu/U Nitrate Soln	Cyl Array	H2O	91.17	0.71	3.240e-06
MST01008	1.0040	0.0014	Pu/U Nitrate Soln	Cyl Array	H2O	91.19	0.71	1.960e-06
MST01009	1.0084	0.0017	Pu/U Nitrate Soln	Cyl Array	H2O	91.61	2.32	2.890e-06
MST01010	1.0053	0.0015	Pu/U Nitrate Soln	Cyl Array	H2O	91.63	2.32	2.250e-06
MST01011	1.0083	0.0017	Pu/U Nitrate Soln	Cyl Array	H2O	91.61	2.32	2.890e-06

APPENDIX A
Summary of PC SCALE-4.4/KENO-Va
Mixed Uranium/Plutonium Validation Calculations
(continued)

Run ID	K-eff	σ	Material	Geometry	Reflector	% Pu Enrich	% U Enrich	σ^2
MST01012	1.0061	0.0015	Pu/U Nitrate Soln	Cyl Array	H2O	91.15	0.71	2.250e-06
MST01013	1.0140	0.0014	Pu/U Nitrate Soln	Cyl Array	H2O	91.15	0.71	1.960e-06
MST02001	1.0121	0.0010	Pu/U Nitrate Soln	Cyl Array	H2O	91.16	0.72	1.000e-06
MST02002	1.0118	0.0013	Pu/U Nitrate Soln	Cyl Array	H2O	91.14	0.72	1.690e-06
MST02003	1.0099	0.0013	Pu/U Nitrate Soln	Cyl Array	H2O	91.14	0.44	1.690e-06
MST04001	1.0048	0.0005	Pu/U Nitrate Soln	Cyl Array	H2O	91.15	0.57	2.500e-07
MST04002	1.0063	0.0016	Pu/U Nitrate Soln	Cyl Array	H2O	91.15	0.57	2.560e-06
MST04003	1.0034	0.0018	Pu/U Nitrate Soln	Cyl Array	H2O	91.15	0.57	3.240e-06
MST04004	1.0047	0.0005	Pu/U Nitrate Soln	Cyl Array	H2O	91.15	0.57	2.500e-07
MST04005	1.0056	0.0004	Pu/U Nitrate Soln	Cyl Array	H2O	91.15	0.57	1.600e-07
MST04006	1.0051	0.0015	Pu/U Nitrate Soln	Cyl Array	H2O	91.15	0.57	2.250e-06
MST04007	1.0056	0.0004	Pu/U Nitrate Soln	Cyl Array	H2O	91.15	0.57	1.600e-07
MST04008	1.0091	0.0004	Pu/U Nitrate Soln	Cyl Array	H2O	91.15	0.57	4.000e-04
MST04009	1.0067	0.0004	Pu/U Nitrate Soln	Cyl Array	H2O	91.15	0.57	1.600e-07
MST05001	0.9966	0.0004	Pu/U Soln in Slab Tank	Cuboid	H2O	91.15	0.57	1.600e-07
MST05002	0.9969	0.0005	Pu/U Soln in Slab Tank	Cuboid	H2O	91.15	0.57	2.500e-07
MST05003	1.0019	0.0005	Pu/U Soln in Slab Tank	Cuboid	H2O	91.15	0.57	2.500e-07
MST05004	1.0056	0.0016	Pu/U Soln in Slab Tank	Cuboid	H2O	91.15	0.57	2.560e-06
MST05005	1.0084	0.0017	Pu/U Soln in Slab Tank	Cuboid	H2O	91.15	0.57	2.890e-06
MST05006	1.0038	0.0017	Pu/U Soln in Slab Tank	Cuboid	H2O	91.15	0.57	2.890e-06
MST05007	1.0086	0.0017	Pu/U Soln in Slab Tank	Cuboid	H2O	91.15	0.57	2.890e-06

Sheet No. 14/15
Calc. No. BUF-04-034
Rev. No. 0

APPENDIX B
Sample Statistical Analysis

Find a single value above which it is predicted with 95% confidence that 99.9% of the critical values will lie (M. G. Natrella, Reference 6, page 2-14):

$P = 0.999$

$g = 0.95$

$\bar{X}$ ≡ Arithmetic mean of the benchmark cases = 1.0028

n ≡ Sample size = 76

s ≡ Population Standard Deviation = 0.0056

T ≡ Factor for one-sided tolerance limit (Reference 6, Page 50)

Then, for $T(n,\gamma,P)$ the table value is:

$T(76, 0.95, 0.999) = 3.6105$

Upper Safety Limit ≡ USL = $X_L = \bar{X} - T_{(n,\gamma,P)}s = 1.0028 - (3.6105)(0.0056) = 0.9827$

Bias* ≡ $k_{calculated} - k_{experimental} = 1.0028 - 1.0000 = (+)0.0028$

*Note: The value of "X_L" also contains the bias (i.e., the bias is included in the expression "$\bar{X} - T_{(n,\gamma,P)}s$").

References and Data Available:
1. Scale 4.4 Manual
2. PSR-6
3. PSR-18
4. NCSE-001
5. NCSE-002
6. Validation Reports in BUF Calc files

Design Criteria: See WVDP-162

Assumptions: See individual Cases and Attachments

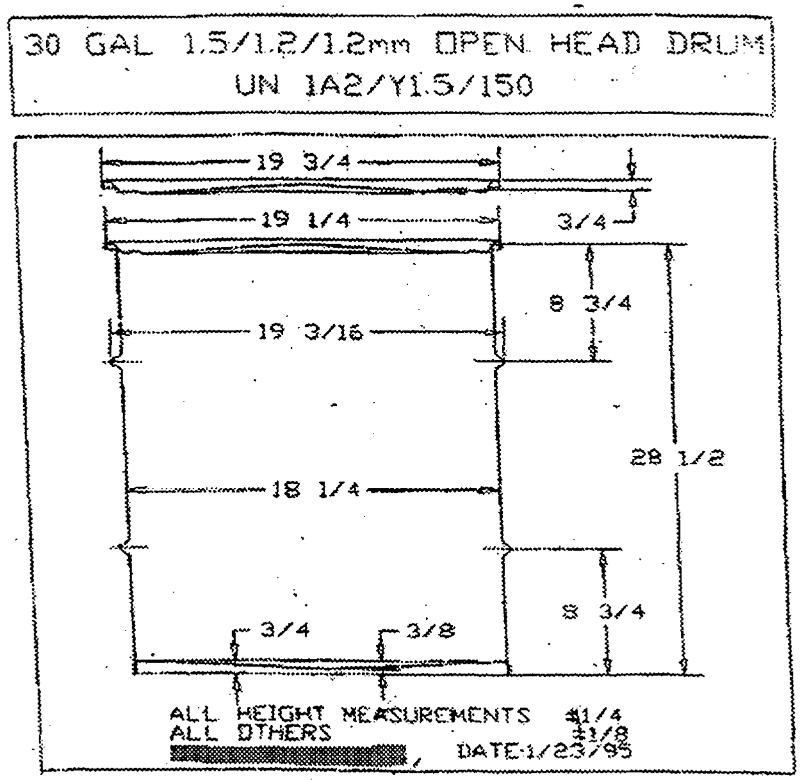
Prepared by:	C Alvin Sweet Signature	3-17-04 Date
Checked by:	[signature] Signature	3/17/04 Date
Approved by:	Joseph C. Wolniewicz Signature	05/11/04 Date

ATTACHMENT 1

COMPONENT GEOMETRIES/ COMPOSITIONS

1. 30 gallon Drum
2. 55 gallon Drum
3. B25 Box
4. Fuel Rod
5. Water Rod
6. 30 gallon Drum with 640 Fuel Rods and 1280 High Density Water Rods
7. 30 gallon Drum with 640 Fuel Rods and 1280 Low Density Water Rods
8. 55 gallon Drum with Sphere of PuO_2
9. B25 Box with Sphere of PuO_2
10. B25 Box with Slab of PuO_2
11. PSR06 Min Box

Figure 1. 30 Gallon Drum (PSR-18)



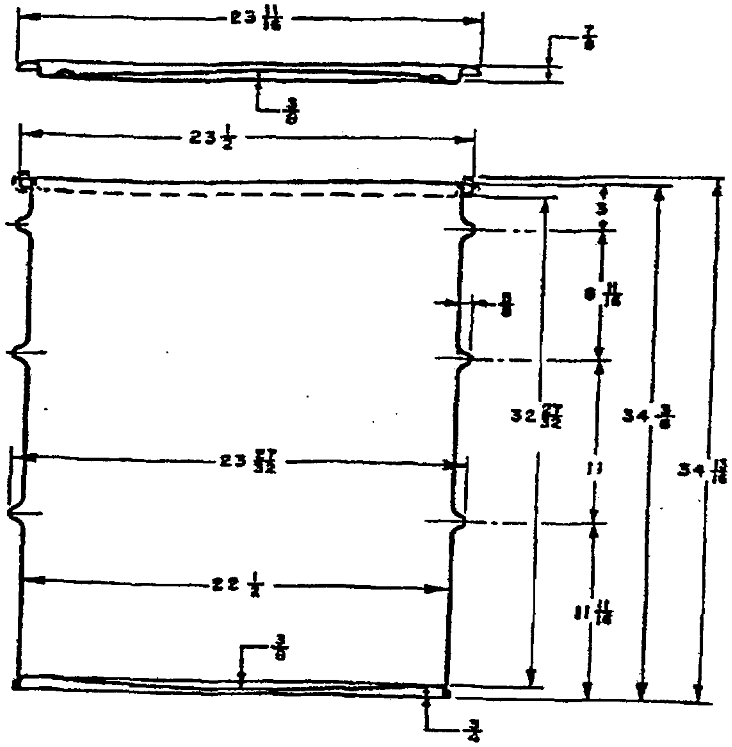
[redacted]

	Drawing	Used in Calc
Ht	28.25" - 28.75"	28.75"
ID	18.125" - 18.375"	18.14"
WT	0.0478"	0.

Figure 2. 55 Gallon Drum (PSR-6)

APPENDIX I

WVNS-EQ-144
Rev. 1

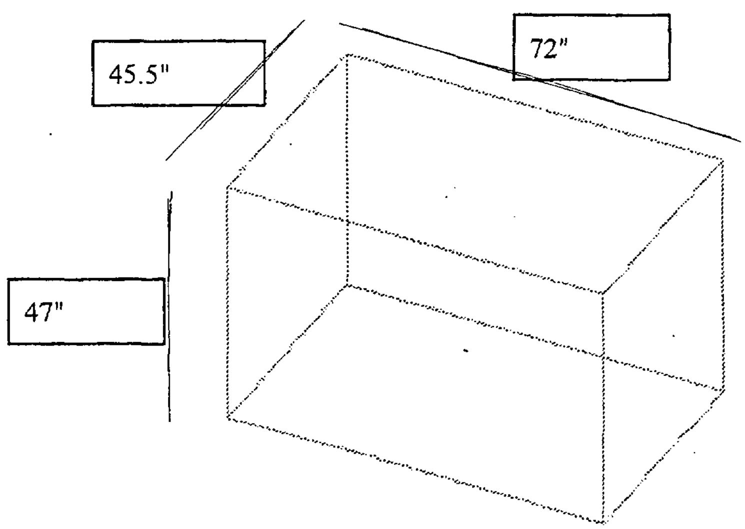


55 GALLON U.S. FULL REMOVABLE HEAD
UNIVERSAL DRUM,

AP-1-4

minimum outer dimensions	Drawing	Used in Calc
Ht 34"	34 13/16"	35.0835"
ID 22"	22.5"	22.37"
WT	0.0598"	0.

Figure 3. B25 Box



	Drawing	Used in Calc
Length	72.04"	72.04"
Width	45.5"	45.5"
Height	46.7"	47.0"

Figure 4. **Fuel Rod**

radius $_{inside}$ * = 0.3785 cm

radius $_{outside}$ * = 0.4318 cm

Length **= 72.3 cm

* WVNS-NCSE-002 (WVDP-EIS-014. Characterization of Reactor Fuel Reprocessed at West Valley)
** arbitrary length to fit in a 30 gal drum

Contents :

	Volume per rod (cm^3)	Mass per rod (g)
$U(5)O_2$	32.54	340.32
SS304	9.8098	77.89
U-235		14.928

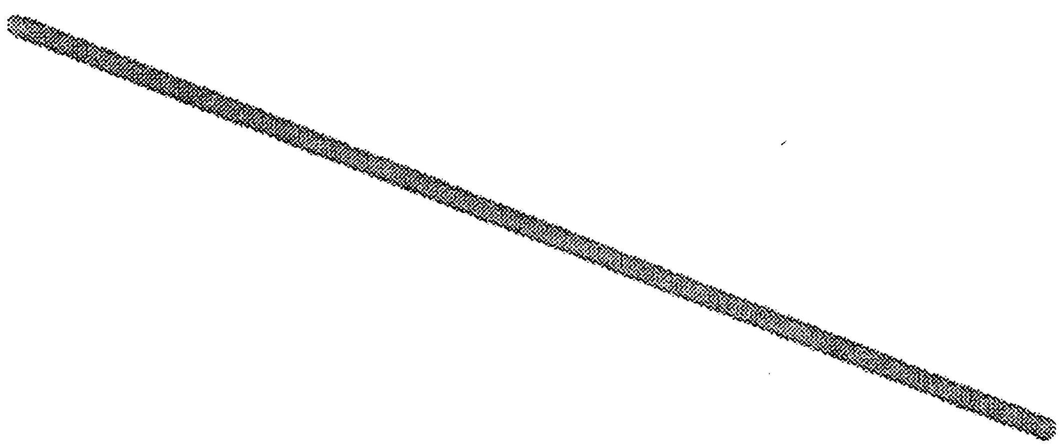


Figure 5. **Water Rod**

radius $_{inside}$ = 0.3785 cm

radius $_{outside}$ = 0.4318 cm

Length = 72.3 cm

Contents :

	Volume per rod (cm^3)	Mass per moderated rod (g)	Mass per unmoderated rod (g)
H_2O	32.54	32.54	1.627
SS304	9.8098	77.89	77.89

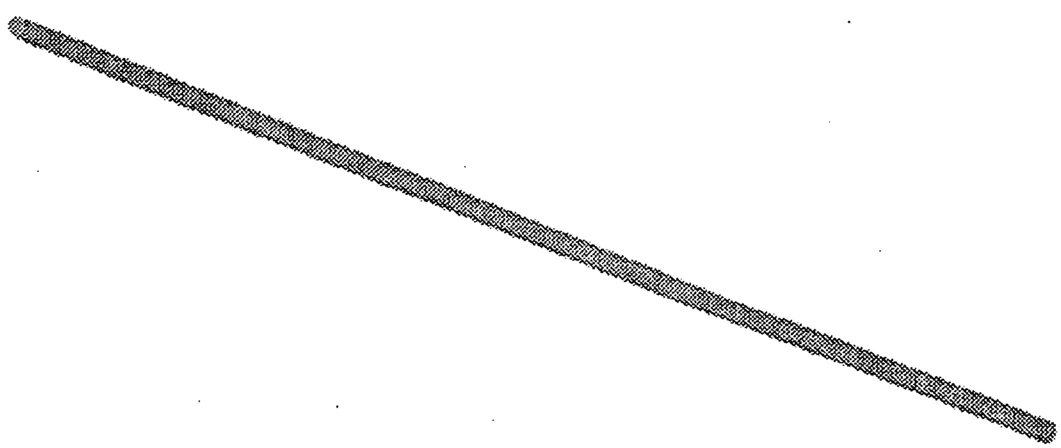


Figure 6. **30 gallon Drum with 640 Fuel Rods and 1280 Full Density Water Rods**

Contents :

	Volume per Drum(cm^3)	Mass per Drum(g)
$U(5)O_2$	20,825.6	217,804.8
SS304	18,834.8	149,548.8
H_2O in water rods	41,651.2	41,651.2
U-235		9,553.9

Space around rods filled with 0.05 water (6,000g H_2O)

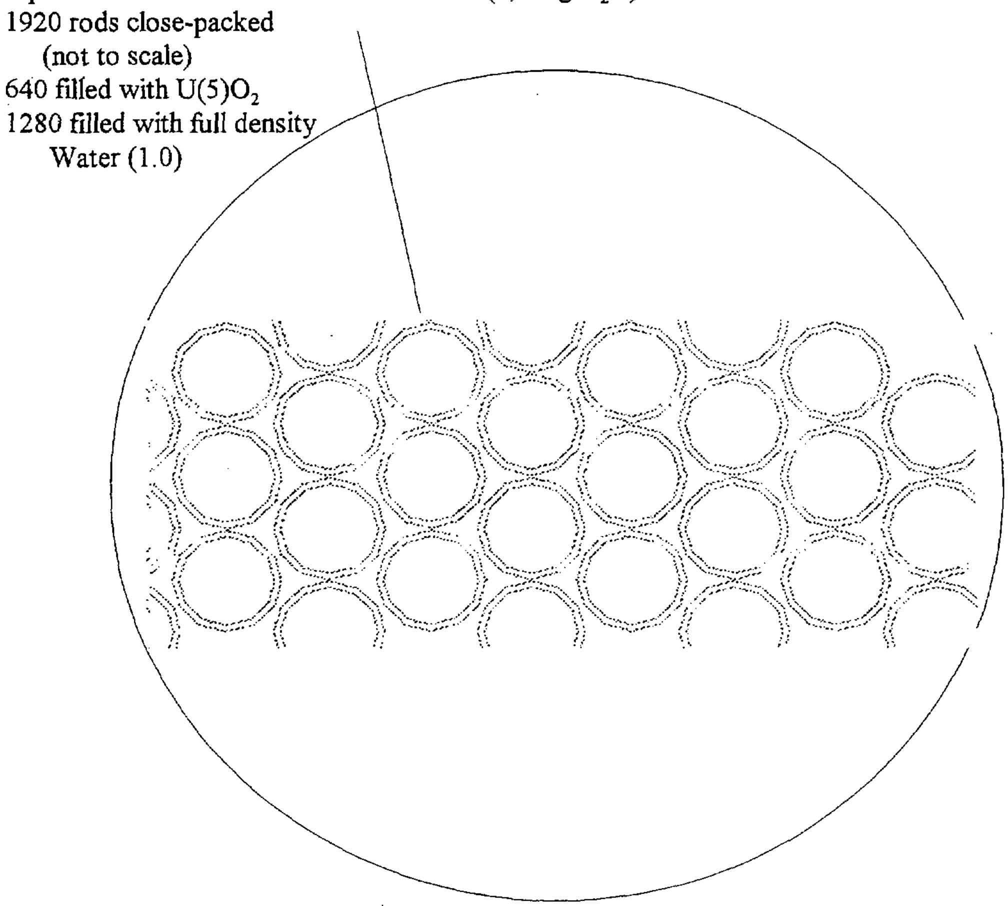


Figure 7. **30 gallon Drum with 640 Fuel Rods and 1280 Low Density Water Rods**

Contents :

	Volume per Drum(cm^3)	Mass per Drum(g)
$U(5)O_2$	20,825.6	217,804.8
SS304	18,834.8	149,548.8
H_2O	2,082.56	2,082.56
U-235		9,553.9

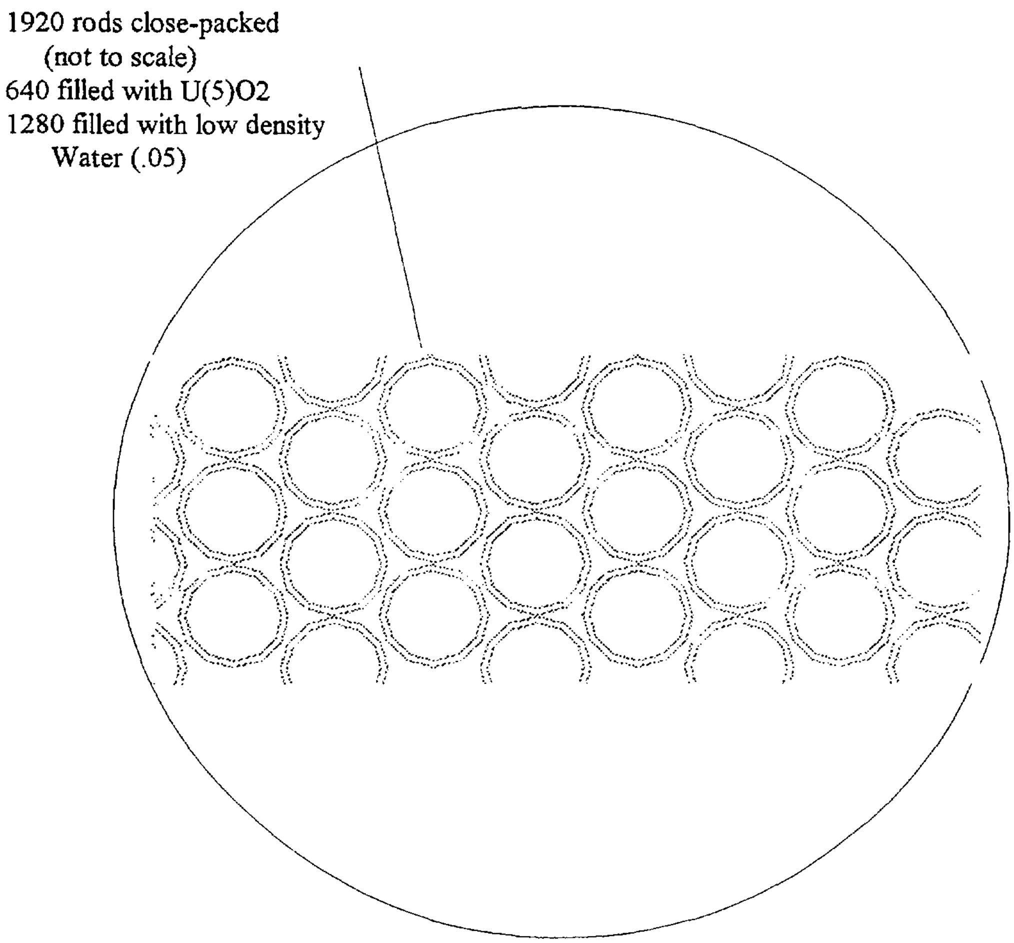


Figure 8. 55 gallon Drum with Sphere of PuO_2

Sphere has a radius of 1.439 cm and is centered in the drum.
There is 125g of Pu-239
The air inside the drum is regular air with a density of .05 H_2O

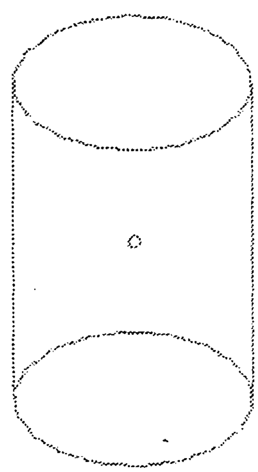


Figure 9. B25 Box with Sphere of PuO_2

There is 200g of Pu-239 in the form of PuO_2.

The air inside the box around the sphere is regular air with a density of 0.05 H_2O.

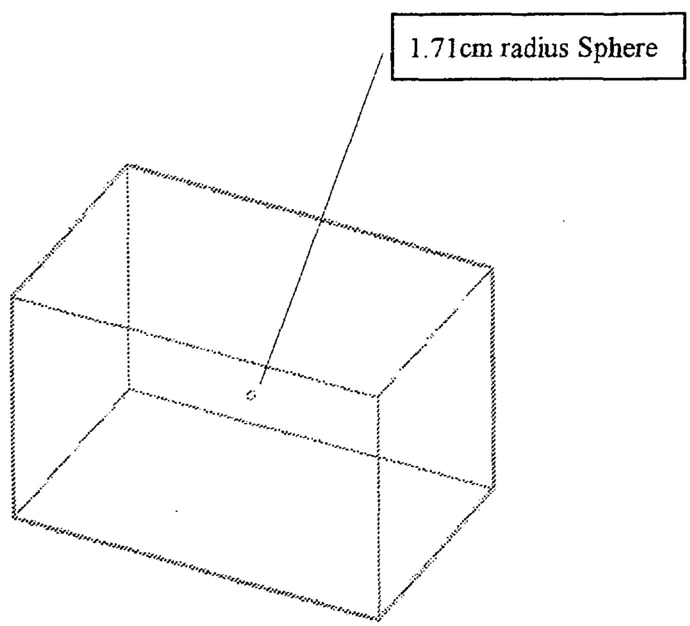


Figure 10. B25 Box with Slab of PuO_2

There is 200g of Pu-239 in the form of PuO_2.

The air inside the box around the slab is regular air with a density of 0.05 H_2O.

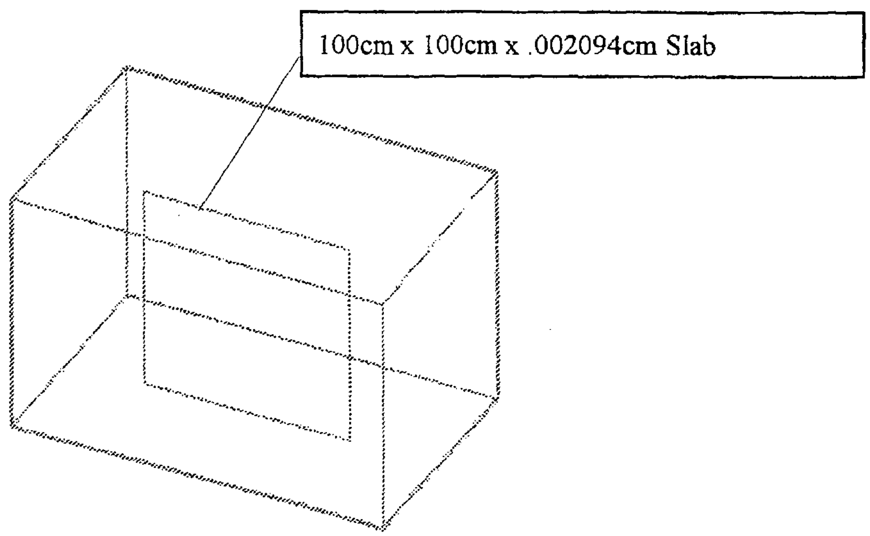
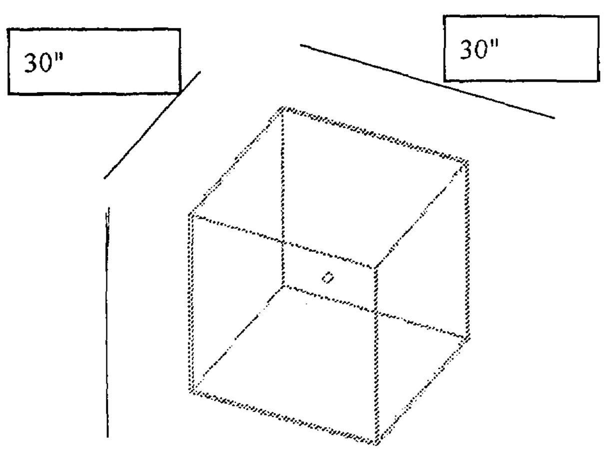


Figure 11. PSR-6 MIN Box



	PSR-6 minimum	Used in Calc
Length	30"	30""
Width	30""	30""
Height	30""	30""

ATTACHMENT 2

KENO Input for CASE BOX11X

Case BOX11X was the worst combination of B25 PSR06 and PSR18 containers that could be modeled. The other cases included some parts of this case. All other cases are on a CD entitled 'NCSE-007'

The subject case description:
3 tiers drums/ 4 tiers B25/ Center (3 tiers of drums including 2 moderated PSR18 drums between 2 normal PSR18 on top and 2 normal PSR18 on bottom. Four arrays of 12 B-25 boxes with 200g Pu-239 slabs tightly packed surrounded by normal PSR18 drums)

```
=csas25    parm=size=2000000
THREE TIERS - 12 PSR18 DRUMS SURROUNDING B25 BOX -
BOX11X
'Four tiers of B25 BOXES
'1921 Fuel Rods per 30gal DRUM'
'1/3 RODS FILLED WITH UO2 5VOL%WATER'
'2/3 RODS FILLED WITH 5VOL% WATER'
'200g Pu-239 in SLAB in THINWALL(1/4IN) B25 BOX
27groupndf4 infhommedium
PUO2 1 .95 293 94239 100. END
H2O  1  .05 END
UO2  5 .95 293 92235 5 92238 95  END
H2O  5 .05 END
'OPTIMIZED MOIST AIR SURROUNDING ALL DRUMS
H2O  2 .3  END
'AIR IN PSR18 DRUMS AND B25 BOX
H2O  6  .05  END
'AIR
H2O  3  .001  END
REG-CONCRETE 4 1.0 END
SS304  7  1.  END
H2O  8  .00129  END
H2O  9  1.0  END
END COMP
THREE TIERS - 12 PSR18 DRUMS SURROUNDING B25 BOX -
BO11x
READ PARAM  NB8=400 GEN=1000 NPG=1660 TBA=5
 NSK=30 NUB=YES END PARAM
READ GEOM
UNIT 1
CUBOID 1 1 100.  0. .002094 0. 100.  0.
'SPHERE 1 1 1.71  ORIGIN  0. 0. 0.
'B25 BOX
UNIT 3
CUBOID 8 1 182.245  .635 114.935 .635 118.745  .635
HOLE 1 38.4 56. .69
CUBOID 7 1 182.88  0.  115.57  0.  119.38  0.
'FUEL ROD WITH UO2

UNIT 4
ZCYLINDER    5   1   .3785  72.3 0. ORIGIN 0. 0.
ZCYLINDER    7   1   .4318  72.3 0. ORIGIN 0. 0.
'FUEL ROD WITH H2O (RHO=0.05)
UNIT 16
ZCYLINDER    6   1   .3785  72.3 0. ORIGIN 0. 0.
ZCYLINDER    7   1   .4318  72.3 0. ORIGIN 0. 0.
'FUEL ROD WITH 100% H2O
UNIT 17
ZCYLINDER    9   1   .3785  72.3 0. ORIGIN 0. 0.
ZCYLINDER    7   1   .4318  72.3 0. ORIGIN 0. 0.

UNIT 23
CUBOID 1 1  180.002094 180. 110.  10.  110.  10.
CUBOID 8 1 182.245  .635 114.935 .635 118.745  .635
CUBOID 7 1 182.88  0.  115.57  0.  119.38  0.

UNIT 24
CUBOID 1 1  2.002094 2. 110.  10.  110.  10.
CUBOID 8 1 182.245  .635 114.935 .635 118.745  .635
CUBOID 7 1 182.88  0.  115.57  0.  119.38  0.


UNIT 5
CUBOID 6 1 4.8 -4.8 4.8 -4.8  72.4 0.
HOLE 4  0. 0. 0.
HOLE 16  .8666  0.  0.
HOLE 16  1.7332  0.  0.
HOLE 4  2.5998  0.  0.
HOLE 16  3.4664  0.  0.
HOLE 16  4.3334  0.  0.
HOLE 4  -.8666  0.  0.
HOLE 16  -1.7332  0.  0.
HOLE 16  -2.5998  0.  0.
HOLE 4  -3.4664  0.  0.
HOLE 16  -4.3334  0.  0.
HOLE 16  0. .8666  0.
HOLE 4  0. 1.7332  0.
HOLE 16  0. 2.5998  0.
HOLE 16  0. 3.4664  0.
HOLE 4  0. 4.3334  0.
HOLE 16  0. -.8666  0.
HOLE 16  0. -1.7332  0.
HOLE 4  0. -2.5998  0.
HOLE 16  0. -3.4664  0.
HOLE 16  0. -4.3334  0.
HOLE 4  .8666 .8666  0.
HOLE 16  -.8666 .8666  0.
HOLE 16  .8666 -.8666  0.
HOLE 4  -.8666 -.8666  0.
HOLE 16  1.7332 1.7332  0.
HOLE 16  -1.7332 1.7332  0.
HOLE 4  1.7332 -1.7332  0.
HOLE 16  -1.7332 -1.7332  0.
HOLE 16  2.5998 2.5998 0.
HOLE 4  -2.5998 2.5998 0.
HOLE 16  2.5998 -2.5998 0.
HOLE 16  -2.5998 -2.5998 0.
HOLE 4  3.4664 3.4664 0.
HOLE 16  -3.4664 3.4664 0.
HOLE 16  3.4664 -3.4664 0.
HOLE 4  -3.4664 -3.4664 0.
HOLE 16  4.3334  4.3334  0.
HOLE 16  -4.3334  4.3334  0.
HOLE 4  4.3334  -4.3334  0.
HOLE 16  -4.3334  -4.3334  0.
HOLE 16 .8666 1.7332  0.
HOLE 4 -.8666 1.7332  0.
HOLE 16 .8666 -1.7332  0.
HOLE 16 -.8666 -1.7332  0.
HOLE 4 .8666 2.5998 0.
HOLE 16 -.8666 2.5998 0.
HOLE 16 .8666 -2.5998 0.
HOLE 4 -.8666 -2.5998 0.
HOLE 16 .8666 3.4664 0.
HOLE 16 -.8666 3.4664 0.
HOLE 4 .8666 -3.4664 0.
HOLE 16 -.8666 -3.4664 0.
HOLE 16 .8666  4.3334 0.
HOLE 4 -.8666  4.3334 0.
HOLE 16 .8666  -4.3334 0.
HOLE 16 -.8666  -4.3334 0.
HOLE 4 1.7332 .8666  0.
HOLE 16 -1.7332 .8666  0.
HOLE 16 1.7332 -.8666  0.
HOLE 4 -1.7332 -.8666  0.
HOLE 16 2.5998 .8666  0.
HOLE 16 -2.5998 .8666  0.
HOLE 4 2.5998 -.8666  0.
HOLE 16 -2.5998 -.8666  0.
HOLE 16 3.4664 .8666  0.
HOLE 4 -3.4664 .8666  0.
HOLE 16 3.4664 -.8666  0.
HOLE 16 -3.4664 -.8666  0.
HOLE 4 4.3334   .8666  0.
HOLE 16 -4.3334   .8666  0.
HOLE 16 4.3334  -.8666  0.
HOLE 4 -4.3334  -.8666  0.
HOLE 16 1.7332 2.5998 0.
HOLE 16 -1.7332 2.5998 0.
HOLE 4 1.7332 -2.5998 0.
HOLE 16 -1.7332 -2.5998 0.
HOLE 16 1.7332 3.4664  0.
HOLE 4 -1.7332 3.4664  0.
HOLE 16 1.7332 -3.4664  0.
HOLE 16 -1.7332 -3.4664  0.
HOLE 4 1.7332 4.3334  0.
HOLE 16 -1.7332 4.3334  0.
HOLE 16 1.7332 -4.3334  0.
HOLE 4 -1.7332 -4.3334  0.
HOLE 16 2.5998  3.4664  0.
HOLE 16 -2.5998  3.4664  0.
HOLE 4 2.5998  -3.4664  0.
HOLE 16 -2.5998  -3.4664  0.
HOLE 16 3.4664 4.3334  0.
HOLE 4 -3.4664 4.3334  0.
HOLE 16 3.4664 -4.3334  0.
HOLE 16 -3.4664 -4.3334  0.
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HOLE 4 2.5998 1.7332 0.
HOLE 16 -2.5998 1.7332 0.
HOLE 16 2.5998 -1.7332 0.
HOLE 4 -2.5998 -1.7332 0.
HOLE 16 3.4664 1.7332 0.
HOLE 16 -3.4664 1.7332 0.
HOLE 4 3.4664 -1.7332 0.
HOLE 16 -3.4664 -1.7332 0.
HOLE 16 4.3334 1.7332 0.
HOLE 4 -4.3334 1.7332 0.
HOLE 16 4.3334 -1.7332 0.
HOLE 16 -4.3334 -1.7332 0.
HOLE 4 3.4664 2.5998 0.
HOLE 16 -3.4664 2.5998 0.
HOLE 16 3.4664 -2.5998 0.
HOLE 4 -3.4664 -2.5998 0.
HOLE 16 4.3334 2.5998 0.
HOLE 16 -4.3334 2.5998 0.
HOLE 4 4.3334 -2.5998 0.
HOLE 16 -4.3334 -2.5998 0.
HOLE 16 4.3334 3.4664 0.
HOLE 4 -4.3334 3.4664 0.
HOLE 16 4.3334 -3.4664 0.
HOLE 16 -4.3334 -3.4664 0.
HOLE 4 2.5998 4.3334 0.
HOLE 16 -2.5998 4.3334 0.
HOLE 16 2.5998 -4.3334 0.
HOLE 4 -2.5998 -4.3334 0.

UNIT 11
CUBOID 6 1 2.167 -2.167 2.167 -2.167 72.4 0.
UNIT 9
CUBOID 6 1 2.167 -2.167 2.167 -2.167 72.4 0.
HOLE 4 0. 0. 0.
HOLE 16 .8666 0. 0.
HOLE 16 1.7332 0. 0.
HOLE 4 -.8666 0. 0.
HOLE 16 -1.7332 0. 0.
HOLE 16 0. .8666 0.
HOLE 4 0. 1.7332 0.
HOLE 16 0. -.8666 0.
HOLE 16 0. -1.7332 0.
HOLE 4 .8666 .8666 0.
HOLE 16 -.8666 .8666 0.
HOLE 16 .8666 -.8666 0.
HOLE 4 -.8666 -.8666 0.
HOLE 16 1.7332 1.7332 0.
HOLE 16 -1.7332 1.7332 0.
HOLE 4 1.7332 -1.7332 0.
HOLE 16 -1.7332 -1.7332 0.
HOLE 16 .8666 1.7332 0.
HOLE 4 -.8666 1.7332 0.
HOLE 16 .8666 -1.7332 0.
HOLE 16 -.8666 -1.7332 0.
HOLE 4 1.7332 .8666 0.
HOLE 16 -1.7332 .8666 0.
HOLE 16 1.7332 -.8666 0.
HOLE 4 -1.7332 -.8666 0.
UNIT 13
CUBOID 6 1 2.167 -2.167 1.3029 -2.1715 72.4 0.
UNIT 12
CUBOID 6 1 2.167 -2.167 1.3029 -2.1715 72.4 0.
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HOLE 16 1.7332 0. 0.
HOLE 4 -.8666 0. 0.
HOLE 16 -1.7332 0. 0.
HOLE 16 0. .8666 0.
HOLE 4 0. -.8666 0.
HOLE 16 0. -1.7332 0.
HOLE 16 .8666 .8666 0.
HOLE 4 -.8666 .8666 0.
HOLE 16 .8666 -.8666 0.
HOLE 16 -.8666 -.8666 0.
HOLE 4 1.7332 -1.7332 0.
HOLE 16 -1.7332 -1.7332 0.
HOLE 16 .8666 -1.7332 0.
HOLE 4 -.8666 -1.7332 0.
HOLE 16 1.7332 .8666 0.
HOLE 16 -1.7332 .8666 0.
HOLE 4 1.7332 -.8666 0.
HOLE 16 -1.7332 -.8666 0.
UNIT 14
CUBOID 6 1 1.3029 -2.1715 2.167 -2.167 72.4 0.
UNIT 15
CUBOID 6 1 1.3029 -2.1715 2.167 -2.167 72.4 0.
HOLE 4 0. 0. 0.
HOLE 16 .8666 0. 0.
HOLE 16 -.8666 0. 0.
HOLE 4 -1.7332 0. 0.
HOLE 16 0. .8666 0.
HOLE 16 0. 1.7332 0.
HOLE 4 0. -.8666 0.
HOLE 16 0. -1.7332 0.
HOLE 16 .8666 .8666 0.
HOLE 4 -.8666 .8666 0.
HOLE 16 .8666 -.8666 0.
HOLE 16 -.8666 -.8666 0.
HOLE 4 -1.7332 1.7332 0.
HOLE 16 -1.7332 -1.7332 0.
HOLE 16 .8666 1.7332 0.
HOLE 4 -.8666 1.7332 0.
HOLE 16 .8666 -1.7332 0.
HOLE 16 -.8666 -1.7332 0.
HOLE 4 -1.7332 .8666 0.
HOLE 16 -1.7332 -.8666 0.
'CONCRETE FLOOR
UNIT 6
CUBOID 4 1 519. -319. 429. -79. 91.44 0.
'30 GAL DRUM
UNIT 7
ZCYLINDER 6 1 23.04 73.025 0. ORIGIN 0.0 0.0
HOLE 4 0. 19.3132 0.
HOLE 16 0. 20.1919 0.
HOLE 16 0. 21.0706 0.
HOLE 4 0. 21.9493 0.
HOLE 16 0. -19.3132 0.
HOLE 16 0. -20.1919 0.
HOLE 4 0. -21.0706 0.
HOLE 16 0. -21.9493 0.
HOLE 16 19.3132 0. 0.
HOLE 4 20.1919 0. 0.
HOLE 16 21.0706 0. 0.
HOLE 16 21.9493 0. 0.
HOLE 4 -19.3132 0. 0.
HOLE 16 -20.1919 0. 0.
HOLE 16 -21.0706 0. 0.
HOLE 4 -21.9493 0. 0.   com='+++'
HOLE 16 .8 19.7522 0.   com='—'
HOLE 16 .8 20.6309 0.
HOLE 4 .8 21.5096 0.
HOLE 16 .8 22.3883 0.
HOLE 16 1.6 19.3132 0.
HOLE 4 1.6 20.1919 0.
HOLE 16 1.6 21.0706 0.
HOLE 16 1.6 21.9493 0.
HOLE 4 2.4 19.7522 0.
HOLE 16 2.4 20.6309 0.
HOLE 16 2.4 21.5096 0.
HOLE 4 3.2 19.3132 0.
HOLE 16 3.2 20.1919 0.
HOLE 16 3.2 21.0706 0.
HOLE 4 4. 19.7522 0.
HOLE 16 4. 20.6309 0.
HOLE 16 4. 21.5096 0.
HOLE 4 4.8 19.3132 0.
HOLE 16 4.8 20.1919 0.
HOLE 16 4.8 21.0706 0.
HOLE 4 5.6 19.7522 0.
HOLE 16 5.6 20.6309 0.
HOLE 16 6.4 19.3132 0.
HOLE 4 6.4 20.1919 0.
HOLE 16 7.2 19.7522 0.
HOLE 16 7.2 20.6309 0.
HOLE 4 8.0 19.3132 0.
HOLE 16 8.0 20.1919 0.
HOLE 16 8.8 19.7522 0.
HOLE 4 9.6 19.3132 0.
```

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HOLE 16 10.4 19.7522 0.
HOLE 16 11.2 19.3132 0.  com='+++'
HOLE 4 .8 -19.7522 0.  com='---'
HOLE 16 .8 -20.6309 0.
HOLE 16 .8 -21.5096 0.
HOLE 4 .8 -22.3883 0.
HOLE 16 1.6 -19.3132 0.
HOLE 16 1.6 -20.1919 0.
HOLE 4 1.6 -21.0706 0.
HOLE 16 1.6 -21.9493 0.
HOLE 16 2.4 -19.7522 0.
HOLE 4 2.4 -20.6309 0.
HOLE 16 2.4 -21.5096 0.
HOLE 16 3.2 -19.3132 0.
HOLE 4 3.2 -20.1919 0.
HOLE 16 3.2 -21.0706 0.
HOLE 16 4. -19.7522 0.
HOLE 4 4. -20.6309 0.
HOLE 16 4. -21.5096 0.
HOLE 16 4.8 -19.3132 0.
HOLE 4 4.8 -20.1919 0.
HOLE 16 4.8 -21.0706 0.
HOLE 16 5.6 -19.7522 0.
HOLE 4 5.6 -20.6309 0.
HOLE 16 6.4 -19.3132 0.
HOLE 16 6.4 -20.1919 0.
HOLE 4 7.2 -19.7522 0.
HOLE 16 7.2 -20.6309 0.
HOLE 16 8.0 -19.3132 0.
HOLE 4 8.0 -20.1919 0.
HOLE 16 8.8 -19.7522 0.
HOLE 16 9.6 -19.3132 0.
HOLE 4 10.4 -19.7522 0.
HOLE 16 11.2 -19.3132 0. com='---'

HOLE 16 -.8 19.7522 0. com='++++'
HOLE 4 -.8 20.6309 0.
HOLE 16 -.8 21.5096 0.
HOLE 16 -.8 22.3883 0.
HOLE 4 -1.6 19.3132 0.
HOLE 16 -1.6 20.1919 0.
HOLE 16 -1.6 21.0706 0.
HOLE 4 -1.6 21.9493 0.
HOLE 16 -2.4 19.7522 0.
HOLE 16 -2.4 20.6309 0.
HOLE 4 -2.4 21.5096 0.
HOLE 16 -3.2 19.3132 0.
HOLE 16 -3.2 20.1919 0.
HOLE 4 -3.2 21.0706 0.
HOLE 16 -4. 19.7522 0.
HOLE 16 -4. 20.6309 0.
HOLE 4 -4. 21.5096 0.
HOLE 16 -4.8 19.3132 0.
HOLE 16 -4.8 20.1919 0.
HOLE 4 -4.8 21.0706 0.
HOLE 16 -5.6 19.7522 0.
HOLE 16 -5.6 20.6309 0.
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HOLE 16 -6.4 20.1919 0.
HOLE 16 -7.2 19.7522 0.
HOLE 4 -7.2 20.6309 0.
HOLE 16 -8.0 19.3132 0.
HOLE 16 -8.0 20.1919 0.
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HOLE 16 -9.6 19.3132 0.
HOLE 16 -10.4 19.7522 0.
HOLE 4 -11.2 19.3132 0. com='----'
HOLE 16 -.8 -19.7522 0. com='++++'
HOLE 16 -.8 -20.6309 0.
HOLE 4 -.8 -21.5096 0.
HOLE 16 -.8 -22.3883 0.
HOLE 16 -1.6 -19.3132 0.
HOLE 4 -1.6 -20.1919 0.
HOLE 16 -1.6 -21.0706 0.
HOLE 16 -1.6 -21.9493 0.
HOLE 4 -2.4 -19.7522 0.
HOLE 16 -2.4 -20.6309 0.
HOLE 16 -2.4 -21.5096 0.
HOLE 4 -3.2 -19.3132 0.
HOLE 16 -3.2 -20.1919 0.
HOLE 16 -3.2 -21.0706 0.
HOLE 4 -4. -19.7522 0.
HOLE 16 -4. -20.6309 0.
HOLE 16 -4. -21.5096 0.
HOLE 4 -4.8 -19.3132 0.
HOLE 16 -4.8 -20.1919 0.
HOLE 16 -4.8 -21.0706 0.
HOLE 4 -5.6 -19.7522 0.
HOLE 16 -5.6 -20.6309 0.
HOLE 16 -6.4 -19.3132 0.
HOLE 4 -6.4 -20.1919 0.
HOLE 16 -7.2 -19.7522 0.
HOLE 16 -7.2 -20.6309 0.
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HOLE 16 -8.0 -20.1919 0.
HOLE 16 -8.8 -19.7522 0.
HOLE 4 -9.6 -19.3132 0.
HOLE 16 -10.4 -19.7522 0.
HOLE 16 -11.2 -19.3132 0.

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HOLE 16 20.6309 .8  0.
HOLE 16 21.5096 .8  0.
HOLE 4 22.3883 .8  0.
HOLE 16  19.3132 1.6  0.
HOLE 16  20.1919 1.6 0.
HOLE 4  21.0706 1.6 0.
HOLE 16  21.9493 1.6 0.
HOLE 16 19.7522 2.4 0.
HOLE 4 20.6309 2.4 0.
HOLE 16 21.5096 2.4 0.
HOLE 16 19.3132 3.2 0.
HOLE 4 20.1919 3.2 0.
HOLE 16 21.0706 3.2 0.
HOLE 16 19.7522 4. 0.
HOLE 4 20.6309 4. 0.
HOLE 16 21.5096 4. 0.
HOLE 16 19.3132 4.8 0.
HOLE 4 20.1919 4.8 0.
HOLE 16 21.0706 4.8 0.
HOLE 16 19.7522 5.6 0.
HOLE 4 20.6309 5.6 0.
HOLE 16 19.3132 6.4 0.
HOLE 16 20.1919 6.4 0.
HOLE 4 19.7522 7.2 0.
HOLE 16 20.6309 7.2 0.
HOLE 16 19.3132 8.0 0.
HOLE 4 20.1919 8.0 0.
HOLE 16 19.7522 8.8 0.
HOLE 16 19.3132 9.6 0.
HOLE 4 19.7522 10.4 0.
HOLE 16 19.3132 11.2 0. com='----'
HOLE 16 -19.7522 .8 0. com='++++'
HOLE 4 -20.6309 .8 0.
HOLE 16 -21.5096 .8 0.
HOLE 16 -22.3883 .8 0.
HOLE 4 -19.3132 1.6 0.
HOLE 16 -20.1919 1.6 0.
HOLE 16 -21.0706 1.6 0.
HOLE 4 -21.9493 1.6 0.
HOLE 16 -19.7522 2.4 0.
HOLE 16 -20.6309 2.4 0.
HOLE 4 -21.5096 2.4 0.
HOLE 16 -19.3132 3.2 0.
HOLE 16 -20.1919 3.2 0.
HOLE 4 -21.0706 3.2 0.
HOLE 16 -19.7522 4. 0.
HOLE 16 -20.6309 4. 0.
HOLE 4 -21.5096 4. 0.
HOLE 16 -19.3132 4.8 0.
HOLE 16 -20.1919 4.8 0.
HOLE 4 -21.0706 4.8 0.
HOLE 16 -19.7522 5.6 0.
HOLE 16 -20.6309 5.6 0.
HOLE 4 -19.3132 6.4 0.
HOLE 16 -20.1919 6.4 0.
HOLE 16 -19.7522 7.2 0.
HOLE 4 -20.6309 7.2 0.
```

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HOLE 4 -19.7522 8.8 0.
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HOLE 16 -19.7522 10.4 0.
HOLE 4 -19.3132 11.2 0. com='---'

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HOLE 16 20.6309 -.8 0.
HOLE 4 21.5096 -.8 0.
HOLE 16 22.3883 -.8 0.
HOLE 16 19.3132 -1.6 0.
HOLE 4 20.1919 -1.6 0.
HOLE 16 21.0706 -1.6 0.
HOLE 16 21.9493 -1.6 0.
HOLE 4 19.7522 -2.4 0.
HOLE 16 20.6309 -2.4 0.
HOLE 16 21.5096 -2.4 0.
HOLE 4 19.3132 -3.2 0.
HOLE 16 20.1919 -3.2 0.
HOLE 16 21.0706 -3.2 0.
HOLE 4 19.7522 -4. 0.
HOLE 16 20.6309 -4. 0.
HOLE 16 21.5096 -4. 0.
HOLE 4 19.3132 -4.8 0.
HOLE 16 20.1919 -4.8 0.
HOLE 16 21.0706 -4.8 0.
HOLE 4 19.7522 -5.6 0.
HOLE 16 20.6309 -5.6 0.
HOLE 16 19.3132 -6.4 0.
HOLE 4 20.1919 -6.4 0.
HOLE 16 19.7522 -7.2 0.
HOLE 16 20.6309 -7.2 0.
HOLE 4 19.3132 -8.0 0.
HOLE 16 20.1919 -8.0 0.
HOLE 16 19.7522 -8.8 0.
HOLE 4 19.3132 -9.6 0.
HOLE 16 19.7522 -10.4 0.
HOLE 16 19.3132 -11.2 0. com='----'
HOLE 4 -19.7522 -.8 0. com='++++'
HOLE 16 -20.6309 -.8 0.
HOLE 16 -21.5096 -.8 0.
HOLE 4 -22.3883 -.8 0.
HOLE 16 -19.3132 -1.6 0.
HOLE 16 -20.1919 -1.6 0.
HOLE 4 -21.0706 -1.6 0.
HOLE 16 -21.9493 -1.6 0.
HOLE 16 -19.7522 -2.4 0.
HOLE 4 -20.6309 -2.4 0.
HOLE 16 -21.5096 -2.4 0.
HOLE 16 -19.3132 -3.2 0.
HOLE 4 -20.1919 -3.2 0.
HOLE 16 -21.0706 -3.2 0.
HOLE 16 -19.7522 -4. 0.
HOLE 4 -20.6309 -4. 0.
HOLE 16 -21.5096 -4. 0.
HOLE 16 -19.3132 -4.8 0.
HOLE 4 -20.1919 -4.8 0.
HOLE 16 -21.0706 -4.8 0.
HOLE 16 -19.7522 -5.6 0.
HOLE 4 -20.6309 -5.6 0.
HOLE 16 -19.3132 -6.4 0.
HOLE 16 -20.1919 -6.4 0.
HOLE 4 -19.7522 -7.2 0.
HOLE 16 -20.6309 -7.2 0.
HOLE 16 -19.3132 -8.0 0.
HOLE 4 -20.1919 -8.0 0.
HOLE 16 -19.7522 -8.8 0.
HOLE 16 -19.3132 -9.6 0.
HOLE 4 -19.7522 -10.4 0.
HOLE 16 -19.3132 -11.2 0.

HOLE 5 0. 0. 0.
HOLE 5 9.7 0. 0.
HOLE 5 0. 9.7 0.
HOLE 5 -9.7 0. 0.
HOLE 9 2.17 16.7 0.
HOLE 9 -2.17 16.7 0.
HOLE 9 6.52 16.7 0.
HOLE 9 -6.52 16.7 0.
HOLE 9 2.17 -16.7 0.
HOLE 9 -2.17 -16.7 0.
HOLE 9 6.52 -16.7 0.
HOLE 9 -6.52 -16.7 0.
HOLE 9 16.7 2.17 0.
HOLE 9 16.7 -2.17 0.
HOLE 9 16.7 6.52 0.
HOLE 9 16.7 -6.52 0.
HOLE 9 -16.7 2.17 0.
HOLE 9 -16.7 -2.17 0.
HOLE 9 -16.7 6.52 0.
HOLE 9 -16.7 -6.52 0.
HOLE 12 -16.7 10.86 0.
HOLE 12 16.7 -9.9914 0.
HOLE 12 16.7 10.86 0.
HOLE 12 -16.7 -9.9914 0.
HOLE 15 10.86 -16.7 0.
HOLE 15 -9.9914 16.7 0.
HOLE 15 10.86 16.7 0.
HOLE 15 -9.9914 -16.7 0.

HOLE 5 0. -9.7 0.
HOLE 5 9.7 9.7 0.
HOLE 5 -9.7 9.7 0.
HOLE 5 9.7 -9.7 0.
HOLE 5 -9.7 -9.7 0.


UNIT 18
CUBOID 6 1 4.8 -4.8 4.8 -4.8 72.4 0.
HOLE 4 0. 0. 0.
HOLE 17 .8666 0. 0.
HOLE 17 1.7332 0. 0.
HOLE 4 2.5998 0. 0.
HOLE 17 3.4664 0. 0.
HOLE 17 4.3334 0. 0.
HOLE 4 -.8666 0. 0.
HOLE 17 -1.7332 0. 0.
HOLE 17 -2.5998 0. 0.
HOLE 4 -3.4664 0. 0.
HOLE 17 -4.3334 0. 0.
HOLE 17 0. .8666 0.
HOLE 4 0. 1.7332 0.
HOLE 17 0. 2.5998 0.
HOLE 17 0. 3.4664 0.
HOLE 4 0. 4.3334 0.
HOLE 17 0. -.8666 0.
HOLE 17 0. -1.7332 0.
HOLE 4 0. -2.5998 0.
HOLE 17 0. -3.4664 0.
HOLE 17 0. -4.3334 0.
HOLE 4 .8666 .8666 0.
HOLE 17 -.8666 .8666 0.
HOLE 17 .8666 -.8666 0.
HOLE 4 -.8666 -.8666 0.
HOLE 17 1.7332 1.7332 0.
HOLE 17 -1.7332 1.7332 0.
HOLE 4 1.7332 -1.7332 0.
HOLE 17 -1.7332 -1.7332 0.
HOLE 17 2.5998 2.5998 0.
HOLE 4 -2.5998 2.5998 0.
HOLE 17 2.5998 -2.5998 0.
HOLE 17 -2.5998 -2.5998 0.
HOLE 4 3.4664 3.4664 0.
HOLE 17 -3.4664 3.4664 0.
HOLE 17 3.4664 -3.4664 0.
HOLE 4 -3.4664 -3.4664 0.
HOLE 17 4.3334 4.3334 0.
HOLE 17 -4.3334 4.3334 0.
HOLE 4 4.3334 -4.3334 0.
HOLE 17 -4.3334 -4.3334 0.
HOLE 17 .8666 1.7332 0.
HOLE 4 -.8666 1.7332 0.
HOLE 17 .8666 -1.7332 0.
HOLE 17 -.8666 -1.7332 0.
HOLE 4 .8666 2.5998 0.
HOLE 17 -.8666 2.5998 0.
HOLE 17 .8666 -2.5998 0.
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HOLE 4 -.8666 -2.5998 0.
HOLE 17 .8666 3.4664 0.
HOLE 17 -.8666 3.4664 0.
HOLE 4 .8666 -3.4664 0.
HOLE 17 -.8666 -3.4664 0.
HOLE 17 .8666 4.3334 0.
HOLE 4 -.8666 4.3334 0.
HOLE 17 .8666 -4.3334 0.
HOLE 17 -.8666 -4.3334 0.
HOLE 4 1.7332 .8666 0.
HOLE 17 -1.7332 .8666 0.
HOLE 17 1.7332 -.8666 0.
HOLE 4 -1.7332 -.8666 0.
HOLE 17 2.5998 .8666 0.
HOLE 17 -2.5998 .8666 0.
HOLE 4 2.5998 -.8666 0.
HOLE 17 -2.5998 -.8666 0.
HOLE 17 3.4664 .8666 0.
HOLE 4 -3.4664 .8666 0.
HOLE 17 3.4664 -.8666 0.
HOLE 17 -3.4664 -.8666 0.
HOLE 4 4.3334 .8666 0.
HOLE 17 -4.3334 .8666 0.
HOLE 17 4.3334 -.8666 0.
HOLE 4 -4.3334 -.8666 0.
HOLE 17 1.7332 2.5998 0.
HOLE 17 -1.7332 2.5998 0.
HOLE 4 1.7332 -2.5998 0.
HOLE 17 -1.7332 -2.5998 0.
HOLE 17 1.7332 3.4664 0.
HOLE 4 -1.7332 3.4664 0.
HOLE 17 1.7332 -3.4664 0.
HOLE 17 -1.7332 -3.4664 0.
HOLE 4 1.7332 4.3334 0.
HOLE 17 -1.7332 4.3334 0.
HOLE 17 1.7332 -4.3334 0.
HOLE 4 -1.7332 -4.3334 0.
HOLE 17 2.5998 3.4664 0.
HOLE 17 -2.5998 3.4664 0.
HOLE 4 2.5998 -3.4664 0.
HOLE 17 -2.5998 -3.4664 0.
HOLE 17 3.4664 4.3334 0.
HOLE 4 -3.4664 4.3334 0.
HOLE 17 3.4664 -4.3334 0.
HOLE 17 -3.4664 -4.3334 0.
HOLE 4 2.5998 1.7332 0.
HOLE 17 -2.5998 1.7332 0.
HOLE 17 2.5998 -1.7332 0.
HOLE 4 -2.5998 -1.7332 0.
HOLE 17 3.4664 1.7332 0.
HOLE 17 -3.4664 1.7332 0.
HOLE 4 3.4664 -1.7332 0.
HOLE 17 -3.4664 -1.7332 0.
HOLE 17 4.3334 1.7332 0.
HOLE 4 -4.3334 1.7332 0.
HOLE 17 4.3334 -1.7332 0.
HOLE 17 -4.3334 -1.7332 0.
HOLE 4 3.4664 2.5998 0.
HOLE 17 -3.4664 2.5998 0.
HOLE 17 3.4664 -2.5998 0.
HOLE 4 -3.4664 -2.5998 0.
HOLE 17 4.3334 2.5998 0.
HOLE 17 -4.3334 2.5998 0.
HOLE 4 4.3334 -2.5998 0.
HOLE 17 -4.3334 -2.5998 0.
HOLE 17 4.3334 3.4664 0.
HOLE 4 -4.3334 3.4664 0.
HOLE 17 4.3334 -3.4664 0.
HOLE 17 -4.3334 -3.4664 0.
HOLE 4 2.5998 4.3334 0.
HOLE 17 -2.5998 4.3334 0.
HOLE 17 2.5998 -4.3334 0.
HOLE 4 -2.5998 -4.3334 0.

UNIT 19
CUBOID 6 1 2.167 -2.167 2.167 -2.167 72.4 0.
HOLE 4 0. 0. 0.
HOLE 17 .8666 0. 0.
HOLE 17 1.7332 0. 0.
HOLE 4 -.8666 0. 0.
HOLE 17 -1.7332 0. 0.
HOLE 17 0. .8666 0.
HOLE 4 0. 1.7332 0.
HOLE 17 0. -.8666 0.
HOLE 17 0. -1.7332 0.
HOLE 4 .8666 .8666 0.
HOLE 17 -.8666 .8666 0.
HOLE 17 .8666 -.8666 0.
HOLE 4 -.8666 -.8666 0.
HOLE 17 1.7332 1.7332 0.
HOLE 17 -1.7332 1.7332 0.
HOLE 4 1.7332 -1.7332 0.
HOLE 17 -1.7332 -1.7332 0.
HOLE 17 .8666 1.7332 0.
HOLE 4 -.8666 1.7332 0.
HOLE 17 .8666 -1.7332 0.
HOLE 17 -.8666 -1.7332 0.
HOLE 4 1.7332 .8666 0.
HOLE 17 -1.7332 .8666 0.
HOLE 17 1.7332 -.8666 0.
HOLE 4 -1.7332 -.8666 0.
UNIT 20
CUBOID 6 1 2.167 -2.167 1.3029 -2.1715 72.4 0.
HOLE 4 0. 0. 0.
HOLE 17 .8666 0. 0.
HOLE 17 1.7332 0. 0.
HOLE 4 -.8666 0. 0.
HOLE 17 -1.7332 0. 0.
HOLE 17 0. .8666 0.
HOLE 4 0. -.8666 0.
HOLE 17 0. -1.7332 0.
HOLE 17 .8666 .8666 0.
HOLE 4 -.8666 .8666 0.
HOLE 17 .8666 -.8666 0.
HOLE 17 -.8666 -.8666 0.
HOLE 4 1.7332 -1.7332 0.
HOLE 17 -1.7332 -1.7332 0.
HOLE 17 .8666 -1.7332 0.
HOLE 4 -.8666 -1.7332 0.
HOLE 17 1.7332 .8666 0.
HOLE 17 -1.7332 .8666 0.
HOLE 4 1.7332 -.8666 0.
HOLE 17 -1.7332 -.8666 0.
UNIT 21
CUBOID 6 1 1.3029 -2.1715 2.167 -2.167 72.4 0.
HOLE 4 0. 0. 0.
HOLE 17 .8666 0. 0.
HOLE 17 -.8666 0. 0.
HOLE 4 -1.7332 0. 0.
HOLE 17 0. .8666 0.
HOLE 17 0. 1.7332 0.
HOLE 4 0. -.8666 0.
HOLE 17 0. -1.7332 0.
HOLE 17 .8666 .8666 0.
HOLE 4 -.8666 .8666 0.
HOLE 17 .8666 -.8666 0.
HOLE 17 -.8666 -.8666 0.
HOLE 4 -1.7332 1.7332 0.
HOLE 17 -1.7332 -1.7332 0.
HOLE 17 .8666 1.7332 0.
HOLE 4 -.8666 1.7332 0.
HOLE 17 .8666 -1.7332 0.
HOLE 17 -.8666 -1.7332 0.
HOLE 4 -1.7332 .8666 0.
HOLE 17 -1.7332 -.8666 0.
'30 GAL DRUM - FULL DENSITY
UNIT 22
ZCYLINDER 6 1 23.04 73.025 0. ORIGIN 0.0 0.0
HOLE 4 0. 19.3132 0.
HOLE 17 0. 20.1919 0.
HOLE 17 0. 21.0706 0.
HOLE 4 0. 21.9493 0.
HOLE 17 0. -19.3132 0.
HOLE 17 0. -20.1919 0.
HOLE 4 0. -21.0706 0.
HOLE 17 0. -21.9493 0.
HOLE 17 19.3132 0. 0.
HOLE 4 20.1919 0. 0.
```

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HOLE 17  21.0706 0.  0.
HOLE 17  21.9493 0.  0.
HOLE 4  -19.3132 0. 0.
HOLE 17  -20.1919 0. 0.
HOLE 17  -21.0706 0. 0.
HOLE 4  -21.9493 0. 0.   com= '+++'
HOLE 17 .8 19.7522 0.    com= '—'
HOLE 17 .8 20.6309 0.
HOLE 4 .8 21.5096 0.
HOLE 17 .8 22.3883 0.
HOLE 17 1.6 19.3132 0.
HOLE 4 1.6 20.1919 0.
HOLE 17 1.6 21.0706 0.
HOLE 17 1.6 21.9493 0.
HOLE 4 2.4 19.7522 0.
HOLE 17 2.4 20.6309 0.
HOLE 17 2.4 21.5096 0.
HOLE 4 3.2 19.3132 0.
HOLE 17 3.2 20.1919 0.
HOLE 17 3.2 21.0706 0.
HOLE 4 4. 19.7522 0.
HOLE 17 4. 20.6309 0.
HOLE 17 4. 21.5096 0.
HOLE 4 4.8 19.3132 0.
HOLE 17 4.8 20.1919 0.
HOLE 17 4.8 21.0706 0.
HOLE 4 5.6 19.7522 0.
HOLE 17 5.6 20.6309 0.
HOLE 17 6.4 19.3132 0.
HOLE 4 6.4 20.1919 0.
HOLE 17 7.2 19.7522 0.
HOLE 17 7.2 20.6309 0.
HOLE 4 8.0 19.3132 0.
HOLE 17 8.0 20.1919 0.
HOLE 17 8.8 19.7522 0.
HOLE 4 9.6 19.3132 0.
HOLE 17 10.4 19.7522 0.
HOLE 17 11.2 19.3132 0. com='+++'
HOLE 4 .8 -19.7522 0.  com='—'
HOLE 17 .8 -20.6309 0.
HOLE 17 .8 -21.5096 0.
HOLE 4 .8 -22.3883 0.
HOLE 17 1.6 -19.3132 0.
HOLE 17 1.6 -20.1919 0.
HOLE 4 1.6 -21.0706 0.
HOLE 17 1.6 -21.9493 0.
HOLE 17 2.4 -19.7522 0.
HOLE 4 2.4 -20.6309 0.
HOLE 17 2.4 -21.5096 0.
HOLE 17 3.2 -19.3132 0.
HOLE 4 3.2 -20.1919 0.
HOLE 17 3.2 -21.0706 0.
HOLE 17 4. -19.7522 0.
HOLE 4 4. -20.6309 0.
HOLE 17 4. -21.5096 0.
HOLE 17 4.8 -19.3132 0.
HOLE 4 4.8 -20.1919 0.
HOLE 17 4.8 -21.0706 0.
HOLE 17 5.6 -19.7522 0.
HOLE 4 5.6 -20.6309 0.
HOLE 17 6.4 -19.3132 0.
HOLE 17 6.4 -20.1919 0.
HOLE 4 7.2 -19.7522 0.
HOLE 17 7.2 -20.6309 0.
HOLE 17 8.0 -19.3132 0.
HOLE 4 8.0 -20.1919 0.
HOLE 17 8.8 -19.7522 0.
HOLE 17 9.6 -19.3132 0.
HOLE 4 10.4 -19.7522 0.
HOLE 17 11.2 -19.3132 0. com='—'

HOLE 17 -.8 19.7522 0. com='++++'
HOLE 4 -.8 20.6309 0.
HOLE 17 -.8 21.5096 0.
HOLE 17 -.8 22.3883 0.
HOLE 4 -1.6 19.3132 0.
HOLE 17 -1.6 20.1919 0.
HOLE 17 -1.6 21.0706 0.
HOLE 4 -1.6 21.9493 0.
HOLE 17 -2.4 19.7522 0.
HOLE 17 -2.4 20.6309 0.
HOLE 4 -2.4 21.5096 0.
HOLE 17 -3.2 19.3132 0.
HOLE 17 -3.2 20.1919 0.
HOLE 4 -3.2 21.0706 0.
HOLE 17 -4. 19.7522 0.
HOLE 17 -4. 20.6309 0.
HOLE 4 -4. 21.5096 0.
HOLE 17 -4.8 19.3132 0.
HOLE 17 -4.8 20.1919 0.
HOLE 4 -4.8 21.0706 0.
HOLE 17 -5.6 19.7522 0.
HOLE 17 -5.6 20.6309 0.
HOLE 4 -6.4 19.3132 0.
HOLE 17 -6.4 20.1919 0.
HOLE 17 -7.2 19.7522 0.
HOLE 4 -7.2 20.6309 0.
HOLE 17 -8.0 19.3132 0.
HOLE 17 -8.0 20.1919 0.
HOLE 4 -8.8 19.7522 0.
HOLE 17 -9.6 19.3132 0.
HOLE 17 -10.4 19.7522 0.
HOLE 4 -11.2 19.3132 0. com='——'
HOLE 17 -.8 -19.7522 0. com='++++'
HOLE 17 -.8 -20.6309 0.
HOLE 4 -.8 -21.5096 0.
HOLE 17 -.8 -22.3883 0.
HOLE 17 -1.6 -19.3132 0.
HOLE 4 -1.6 -20.1919 0.
HOLE 17 -1.6 -21.0706 0.
HOLE 17 -1.6 -21.9493 0.
HOLE 4 -2.4 -19.7522 0.
HOLE 17 -2.4 -20.6309 0.
HOLE 17 -2.4 -21.5096 0.
HOLE 4 -3.2 -19.3132 0.
HOLE 17 -3.2 -20.1919 0.
HOLE 17 -3.2 -21.0706 0.
HOLE 4 -4. -19.7522 0.
HOLE 17 -4. -20.6309 0.
HOLE 17 -4. -21.5096 0.
HOLE 4 -4.8 -19.3132 0.
HOLE 17 -4.8 -20.1919 0.
HOLE 17 -4.8 -21.0706 0.
HOLE 4 -5.6 -19.7522 0.
HOLE 17 -5.6 -20.6309 0.
HOLE 17 -6.4 -19.3132 0.
HOLE 4 -6.4 -20.1919 0.
HOLE 17 -7.2 -19.7522 0.
HOLE 17 -7.2 -20.6309 0.
HOLE 4 -8.0 -19.3132 0.
HOLE 17 -8.0 -20.1919 0.
HOLE 17 -8.8 -19.7522 0.
HOLE 4 -9.6 -19.3132 0.
HOLE 17 -10.4 -19.7522 0.
HOLE 17 -11.2 -19.3132 0.

HOLE 4 19.7522 .8  0. com='++++'
HOLE 17 20.6309 .8  0.
HOLE 17 21.5096 .8  0.
HOLE 4 22.3883 .8  0.
HOLE 17  19.3132 1.6  0.
HOLE 17  20.1919 1.6 0.
HOLE 4  21.0706 1.6 0.
HOLE 17  21.9493 1.6 0.
HOLE 17 19.7522 2.4 0.
HOLE 4 20.6309 2.4 0.
HOLE 17 21.5096 2.4 0.
HOLE 17 19.3132 3.2 0.
HOLE 4 20.1919 3.2 0.
HOLE 17 21.0706 3.2 0.
HOLE 17 19.7522 4. 0.
HOLE 4 20.6309 4. 0.
HOLE 17 21.5096 4. 0.
HOLE 17 19.3132 4.8 0.
HOLE 4 20.1919 4.8 0.
HOLE 17 21.0706 4.8 0.
HOLE 17 19.7522 5.6 0.
HOLE 4 20.6309 5.6 0.
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HOLE 17 19.3132 6.4 0.
HOLE 17 20.1919 6.4 0.
HOLE 4 19.7522 7.2 0.
HOLE 17 20.6309 7.2 0.
HOLE 17 19.3132 8.0 0.
HOLE 4 20.1919 8.0 0.
HOLE 17 19.7522 8.8 0.
HOLE 17 19.3132 9.6 0.
HOLE 4 19.7522 10.4 0.
HOLE 17 19.3132 11.2 0. com='----'
HOLE 17 -19.7522 .8 0. com='++++'
HOLE 4 -20.6309 .8 0.
HOLE 17 -21.5096 .8 0.
HOLE 17 -22.3883 .8 0.
HOLE 4 -19.3132 1.6 0.
HOLE 17 -20.1919 1.6 0.
HOLE 17 -21.0706 1.6 0.
HOLE 4 -21.9493 1.6 0.
HOLE 17 -19.7522 2.4 0.
HOLE 17 -20.6309 2.4 0.
HOLE 4 -21.5096 2.4 0.
HOLE 17 -19.3132 3.2 0.
HOLE 17 -20.1919 3.2 0.
HOLE 4 -21.0706 3.2 0.
HOLE 17 -19.7522 4. 0.
HOLE 17 -20.6309 4. 0.
HOLE 4 -21.5096 4. 0.
HOLE 17 -19.3132 4.8 0.
HOLE 17 -20.1919 4.8 0.
HOLE 4 -21.0706 4.8 0.
HOLE 17 -19.7522 5.6 0.
HOLE 17 -20.6309 5.6 0.
HOLE 4 -19.3132 6.4 0.
HOLE 17 -20.1919 6.4 0.
HOLE 17 -19.7522 7.2 0.
HOLE 4 -20.6309 7.2 0.
HOLE 17 -19.3132 8.0 0.
HOLE 17 -20.1919 8.0 0.
HOLE 4 -19.7522 8.8 0.
HOLE 17 -19.3132 9.6 0.
HOLE 17 -19.7522 10.4 0.
HOLE 4 -19.3132 11.2 0. com='---'

HOLE 17 19.7522 -.8 0. com='++++'
HOLE 17 20.6309 -.8 0.
HOLE 4 21.5096 -.8 0.
HOLE 17 22.3883 -.8 0.
HOLE 17 19.3132 -1.6 0.
HOLE 4 20.1919 -1.6 0.
HOLE 17 21.0706 -1.6 0.
HOLE 17 21.9493 -1.6 0.
HOLE 4 19.7522 -2.4 0.
HOLE 17 20.6309 -2.4 0.
HOLE 17 21.5096 -2.4 0.
HOLE 4 19.3132 -3.2 0.
HOLE 17 20.1919 -3.2 0.
HOLE 17 21.0706 -3.2 0.
HOLE 4 19.7522 -4. 0.
HOLE 17 20.6309 -4. 0.
HOLE 17 21.5096 -4. 0.
HOLE 4 19.3132 -4.8 0.
HOLE 17 20.1919 -4.8 0.
HOLE 17 21.0706 -4.8 0.
HOLE 4 19.7522 -5.6 0.
HOLE 17 20.6309 -5.6 0.
HOLE 17 19.3132 -6.4 0.
HOLE 4 20.1919 -6.4 0.
HOLE 17 19.7522 -7.2 0.
HOLE 17 20.6309 -7.2 0.
HOLE 4 19.3132 -8.0 0.
HOLE 17 20.1919 -8.0 0.
HOLE 17 19.7522 -8.8 0.
HOLE 4 19.3132 -9.6 0.
HOLE 17 19.7522 -10.4 0.
HOLE 17 19.3132 -11.2 0. com='----'
HOLE 4 -19.7522 -.8 0. com='++++'
HOLE 17 -20.6309 -.8 0.
HOLE 17 -21.5096 -.8 0.
HOLE 4 -22.3883 -.8 0.
HOLE 17 -19.3132 -1.6 0.
HOLE 17 -20.1919 -1.6 0.
HOLE 4 -21.0706 -1.6 0.
HOLE 17 -21.9493 -1.6 0.
HOLE 17 -19.7522 -2.4 0.
HOLE 4 -20.6309 -2.4 0.
HOLE 17 -21.5096 -2.4 0.
HOLE 17 -19.3132 -3.2 0.
HOLE 4 -20.1919 -3.2 0.
HOLE 17 -21.0706 -3.2 0.
HOLE 17 -19.7522 -4. 0.
HOLE 4 -20.6309 -4. 0.
HOLE 17 -21.5096 -4. 0.
HOLE 17 -19.3132 -4.8 0.
HOLE 4 -20.1919 -4.8 0.
HOLE 17 -21.0706 -4.8 0.
HOLE 17 -19.7522 -5.6 0.
HOLE 4 -20.6309 -5.6 0.
HOLE 17 -19.3132 -6.4 0.
HOLE 17 -20.1919 -6.4 0.
HOLE 4 -19.7522 -7.2 0.
HOLE 17 -20.6309 -7.2 0.
HOLE 17 -19.3132 -8.0 0.
HOLE 4 -20.1919 -8.0 0.
HOLE 17 -19.7522 -8.8 0.
HOLE 17 -19.3132 -9.6 0.
HOLE 4 -19.7522 -10.4 0.
HOLE 17 -19.3132 -11.2 0.

HOLE 18 0. 0. 0.
HOLE 18 9.7 0. 0.
HOLE 18 0. 9.7 0.
HOLE 18 -9.7 0. 0.
HOLE 19 2.17 16.7 0.
HOLE 19 -2.17 16.7 0.
HOLE 19 6.52 16.7 0.
HOLE 19 -6.52 16.7 0.
HOLE 19 2.17 -16.7 0.
HOLE 19 -2.17 -16.7 0.
HOLE 19 6.52 -16.7 0.
HOLE 19 -6.52 -16.7 0.
HOLE 19  16.7 2.17 0.
HOLE 19  16.7 -2.17 0.
HOLE 19 16.7 6.52 0.
HOLE 19  16.7 -6.52 0.
HOLE 19 -16.7 2.17  0.
HOLE 19 -16.7 -2.17  0.
HOLE 19 -16.7 6.52 0.
HOLE 19 -16.7 -6.52  0.
HOLE 20 -16.7 10.86  0.
HOLE 20 16.7 -9.9914  0.
HOLE 20 16.7 10.86  0.
HOLE 20 -16.7 -9.9914  0.
HOLE 21  10.86 -16.7  0.
HOLE 21  -9.9914 16.7  0.
HOLE 21  10.86 16.7  0.
HOLE 21  -9.9914  -16.7 0.

HOLE 18 0. -9.7 0.
HOLE 18 9.7 9.7 0.
HOLE 18 -9.7 9.7 0.
HOLE 18 9.7 -9.7 0.
HOLE 18 -9.7 -9.7 0.

COM="BENCHMARK- START SOURCE SPHERE"
UNIT 10
SPHERE 2 1 2.5  ORIGIN 0. 0. 0.
GLOBAL
UNIT 8
CUBOID 2 1 520. -320. 430  -80.  510. -91.45
HOLE 3  0. 0. 0.
HOLE 7  -23.54 34. 0.0
HOLE 7  -23.54 81. 0.0
HOLE 7  34. 139.11  0.0
HOLE 7   81. 139.11 0.0
HOLE 6  0. 0. -91.44
HOLE 7  128. 139.11  0.
HOLE 7   175. 139.11 0.
HOLE 7  206 42 34.  0.
```

```
HOLE 7 206.42 81. 0.
HOLE 7 34. -23.54 0.
HOLE 7 81. -23.54 0.
HOLE 7 128. -23.54 0.
HOLE 7 175. -23.54 0.
HOLE 22 123.041 185.192 74.
HOLE 22 76.955 185.192 74.
HOLE 7 123.041 185.192 0.
HOLE 7 76.955 185.192 0.
HOLE 7 123.041 185.192 148.
HOLE 7 76.955 185.192 148.

HOLE 3 0. 256. 0.
HOLE 7 -23.54 289. 0.0
HOLE 7 -23.54 336. 0.0
HOLE 7 34. 395.11 0.0
HOLE 7 81. 395.11 0.0
HOLE 7 128. 395.11 0.
HOLE 7 175. 395.11 0.
HOLE 7 206.42 289. 0.
HOLE 7 206.42 336. 0.
HOLE 7 34. 232.54 0.
HOLE 7 81. 232.54 0.
HOLE 7 128. 232.54 0.
HOLE 7 175. 232.54 0.

HOLE 23 -242. 120. 0.
HOLE 7 -265.502 154. 0.0
HOLE 7 -265.502 201. 0.0
HOLE 7 -207.962 259.11 0.0
HOLE 7 -160.962 259.11 0.0
HOLE 7 -113.962 259.11 0.
HOLE 7 -66.962 259.11 0.
HOLE 7 -22.542 154. 0.
HOLE 7 -22.542 201. 0.
HOLE 7 -207.962 96.46 0.
HOLE 7 -160.962 96.46 0.
HOLE 7 -113.962 96.46 0.
HOLE 7 -66.962 96.46 0.

HOLE 23 -242. 120. 120.
HOLE 7 -265.502 154. 74.0
HOLE 7 -265.502 201. 74.0
HOLE 7 -207.962 259.11 74.0
HOLE 7 -160.962 259.11 74.0
HOLE 7 -113.962 259.11 74.
HOLE 7 -66.962 259.11 74.
HOLE 7 -22.542 154. 74.
HOLE 7 -22.542 201. 74.
HOLE 7 -207.962 96.46 74.
HOLE 7 -160.962 96.46 74.
HOLE 7 -113.962 96.46 74.
HOLE 7 -66.962 96.46 74.
'
HOLE 24 242. 120. 0.
HOLE 7 218.7 154.3 0.0
HOLE 7 218.422 201. 0.0
HOLE 7 275.962 259.11 0.0
HOLE 7 322.962 259.11 0.0
HOLE 7 369.962 259.11 0.
HOLE 7 416.962 259.11 0.
HOLE 7 448.382 154. 0.
HOLE 7 448.382 201. 0.
HOLE 7 275.962 96.46 0.
HOLE 7 322.962 96.46 0.
HOLE 7 369.962 96.46 0.
HOLE 7 416.962 96.46 0.

HOLE 23 -242. 120. 240.
HOLE 23 -242. 120. 360.
HOLE 7 -265.502 154. 148.0
HOLE 7 -265.502 201. 148.0
HOLE 7 -207.962 259.11 148.0
HOLE 7 -160.962 259.11 148.0
HOLE 7 -113.962 259.11 148.
HOLE 7 -66.962 259.11 148.
HOLE 7 -22.542 154. 148.
HOLE 7 -22.542 201. 148.
HOLE 7 -207.962 96.46 148.
HOLE 7 -160.962 96.46 148.
HOLE 7 -113.962 96.46 148.
HOLE 7 -66.962 96.46 148.

HOLE 24 242. 120. 120.
HOLE 7 218.7 154.3 74.0
HOLE 7 218.422 201. 74.0
HOLE 7 275.962 259.11 74.0
HOLE 7 322.962 259.11 74.0
HOLE 7 369.962 259.11 74.
HOLE 7 416.962 259.11 74.
HOLE 7 448.382 154. 74.
HOLE 7 448.382 201. 74.
HOLE 7 275.962 96.46 74.
HOLE 7 322.962 96.46 74.
HOLE 7 369.962 96.46 74.
HOLE 7 416.962 96.46 74.
'
'
HOLE 24 242. 120. 240.
HOLE 24 242. 120. 360.
HOLE 7 218.7 154.3 148.0
HOLE 7 218.422 201. 148.0
HOLE 7 275.962 259.11 148.0
HOLE 7 322.962 259.11 148.0
HOLE 7 369.962 259.11 148.
HOLE 7 416.962 259.11 148.
HOLE 7 448.382 154. 148.
HOLE 7 448.382 201. 148.
HOLE 7 275.962 96.46 148.
HOLE 7 322.962 96.46 148.
HOLE 7 369.962 96.46 148.
HOLE 7 416.962 96.46 148.

HOLE 3 0. 0. 120.
HOLE 7 -23.54 34. 74.0
HOLE 7 -23.54 81. 74.0
HOLE 7 34. 139.11 74.0
HOLE 7 81. 139.11 74.0
HOLE 7 128. 139.11 74.
HOLE 7 175. 139.11 74.
HOLE 7 206.42 34. 74.
HOLE 7 206.42 81. 74.
HOLE 7 34. -23.54 74.
HOLE 7 81. -23.54 74.
HOLE 7 128 -23.54 74.
HOLE 7 175. -23.54 74.

HOLE 3 0. 0. 240.
HOLE 3 0. 0. 360.
HOLE 7 -23.54 34. 148.0
HOLE 7 -23.54 81. 148.0
HOLE 7 34. 139.11 148.0
HOLE 7 81. 139.11 148.0
HOLE 7 128. 139.11 148.
HOLE 7 175. 139.11 148.
HOLE 7 206.42 34. 148.
HOLE 7 206.42 81. 148.
HOLE 7 34. -23.54 148.
HOLE 7 81. -23.54 148.
HOLE 7 128. -23.54 148.
HOLE 7 175. -23.54 148.

HOLE 3 0. 256. 120.
HOLE 7 -23.54 289. 74.0
HOLE 7 -23.54 336. 74.0
HOLE 7 34. 395.11 74.0
HOLE 7 81. 395.11 74.0
HOLE 7 128. 395.11 74.
HOLE 7 175. 395.11 74.
HOLE 7 206.42 289. 74.
HOLE 7 206.42 336. 74.
HOLE 7 34. 232.54 74.
HOLE 7 81. 232.54 74.
HOLE 7 128. 232.54 74.
```

```
HOLE 7  175. 232.54  74.

HOLE 3  0. 256. 240.
HOLE 3  0. 256. 360.
HOLE 7  -23.54 289. 148.0
HOLE 7  -23.54 336. 148.0
HOLE 7  34. 395.11  148.0
HOLE 7  81. 395.11 148.0
HOLE 7  128. 395.11  148.
HOLE 7  175. 395.11 148.
HOLE 7  206.42 289.  148.
HOLE 7  206.42 336.  148.
HOLE 7  34. 232.54  148.
HOLE 7  81. 232.54  148.
HOLE 7  128. 232.54  148.
HOLE 7  175. 232.54  148.

'HOLE 10 -62 176. 59.69
'HOLE 10 244. 176. 59.69
END GEOM
READ BOUNDS XFC=MIRROR YFC=MIRROR END BOUNDS
READ START NST=6
TFX=91.4 TFY=56. TFZ=59.69 LNU=10
TFX=91.4 TFY=312. TFZ=59.69 LNU=20

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TFX=-23.54  TFY=81. TFZ=36. LNU=40
TFX=-23.54  TFY=289. TFZ=36. LNU=50
TFX=-23.54  TFY=336. TFZ=36. LNU=60

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TFX=81. TFY=139.11 TFZ=36. LNU=80
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TFX=81. TFY=395.11 TFZ=36. LNU=100

TFX=128. TFY=139.11 TFZ=36. LNU=110
TFX=175. TFY=139.11 TFZ=36. LNU=120
TFX=128. TFY=395.11 TFZ=36. LNU=130
TFX=175. TFY=395.11 TFZ=36. LNU=140

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TFX=206.42 TFY=81. TFZ=36. LNU=160
TFX=206.42 TFY=289. TFZ=36. LNU=170
TFX=206.42 TFY=336. TFZ=36. LNU=180

TFX=34. TFY=-23.54 TFZ=36. LNU=190
TFX=81. TFY=-23.54 TFZ=36. LNU=200
TFX=34. TFY=232.54 TFZ=36. LNU=210
TFX=81. TFY=232.54 TFZ=36. LNU=220

TFX=128. TFY=-23.54 TFZ=36. LNU=230
TFX=175. TFY=-23.54 TFZ=36. LNU=240
TFX=128. TFY=232.54 TFZ=36. LNU=250
TFX=175. TFY=232.54 TFZ=36. LNU=260


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TFX=91.4 TFY=312. TFZ=180. LNU=280

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TFX=-23.54  TFY=336. TFZ=108. LNU=320

TFX=34. TFY=139.11 TFZ=108. LNU=330
TFX=81. TFY=139.11 TFZ=108. LNU=340
TFX=34. TFY=395.11 TFZ=108. LNU=350
TFX=81. TFY=395.11 TFZ=108. LNU=360

TFX=128. TFY=139.11 TFZ=108. LNU=370
TFX=175. TFY=139.11 TFZ=108. LNU=380
TFX=128. TFY=395.11 TFZ=108. LNU=390
TFX=175. TFY=395.11 TFZ=108. LNU=400

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TFX=206.42 TFY=81. TFZ=108. LNU=420
TFX=206.42 TFY=289. TFZ=108. LNU=430
TFX=206.42 TFY=336. TFZ=108. LNU=440

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TFX=34. TFY=232.54 TFZ=108. LNU=470
TFX=81. TFY=232.54 TFZ=108. LNU=480

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TFX=175. TFY=-23.54 TFZ=108. LNU=500
TFX=128. TFY=232.54 TFZ=108. LNU=510
TFX=175. TFY=232.54 TFZ=108. LNU=520

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TFX=-23.54  TFY=289. TFZ=184. LNU=570
TFX=-23.54  TFY=336. TFZ=184. LNU=580

TFX=34. TFY=139.11 TFZ=184. LNU=590
TFX=81. TFY=139.11 TFZ=184. LNU=600
TFX=34. TFY=395.11 TFZ=184. LNU=610
TFX=81. TFY=395.11 TFZ=184. LNU=620

TFX=128. TFY=139.11 TFZ=184. LNU=630
TFX=175. TFY=139.11 TFZ=184. LNU=640
TFX=128. TFY=395.11 TFZ=184. LNU=650
TFX=175. TFY=395.11 TFZ=184. LNU=660

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TFX=34. TFY=232.54 TFZ=184. LNU=730
TFX=81. TFY=232.54 TFZ=184. LNU=740

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TFX=175. TFY=-23.54 TFZ=184. LNU=760
TFX=128. TFY=232.54 TFZ=184. LNU=770
TFX=175. TFY=232.54 TFZ=184. LNU=780


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TFX=76.955 TFY=185.192 TFZ=36. LNU=820
TFX=123.041 TFY=185.192 TFZ=184. LNU=830
TFX=76.955 TFY=185.192 TFZ=184. LNU=840


TFX=-62 TFY=176. TFZ=59.69 LNU=850
TFX=-265.502 TFY=154. TFZ=36.0 LNU=860
TFX=-265.502 TFY=201. TFZ=36.0 LNU=870
TFX=-207.962 TFY=259.11  TFZ=36.0 LNU=880
TFX=-160.962 TFY=259.11 TFZ=36.0 LNU=890
TFX=-113.962 TFY=259.11  TFZ=36. LNU=900
TFX=-66.962 TFY=259.11 TFZ=36. LNU=910
TFX=-22.542 TFY=154.  TFZ=36. LNU=920
TFX=-22.542 TFY=201.  TFZ=36. LNU=930
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TFX=-160.962 TFY=96.46  TFZ=36. LNU=950
TFX=-113.962 TFY=96.46  TFZ=36. LNU=960
TFX=-66.962 TFY=96.46  TFZ=36. LNU=970

TFX=-62 TFY=176. TFZ=179.69 LNU=980
TFX=-265.502 TFY=154. TFZ=111.0 LNU=990
TFX=-265.502 TFY=201. TFZ=111.0 LNU=1000
TFX=-207.962 TFY=259.11  TFZ=111.0 LNU=1010
TFX=-160.962 TFY=259.11 TFZ=111.0 LNU=1020
TFX=-113.962 TFY=259.11  TFZ=111. LNU=1030
TFX=-66.962 TFY=259.11 TFZ=111. LNU=1040
TFX=-22.542 TFY=154.  TFZ=111. LNU=1050
TFX=-22.542 TFY=201.  TFZ=111. LNU=1060
TFX=-207.962 TFY=96.46  TFZ=111. LNU=1070
TFX=-160.962 TFY=96.46  TFZ=111. LNU=1080
TFX=-113.962 TFY=96.46  TFZ=111. LNU=1090
TFX=-66.962 TFY=96.46  TFZ=111. LNU=1100
```

```
TFX=-62 TFY=176. TFZ=300. LNU=1110
TFX=-265.502 TFY=154. TFZ=184.0 LNU=1120
TFX=-265.502 TFY=201. TFZ=184.0 LNU=1130
TFX=-207.962 TFY=259.11 TFZ=184.0 LNU=1140
TFX=-160.962 TFY=259.11 TFZ=184.0 LNU=1150
TFX=-113.962 TFY=259.11 TFZ=184. LNU=1160
TFX=-66.962 TFY=259.11 TFZ=184. LNU=1170
TFX=-22.542 TFY=154. TFZ=184. LNU=1180
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TFX=-207.962 TFY=96.46 TFZ=184. LNU=1200
TFX=-160.962 TFY=96.46 TFZ=184. LNU=1210
TFX=-113.962 TFY=96.46 TFZ=184. LNU=1220
TFX=-66.962 TFY=96.46 TFZ=184. LNU=1230
'
TFX=244. TFY=176. TFZ=59.69 LNU=1240
TFX=218.7 TFY=154.3 TFZ=36.0 LNU=1250
TFX=218.422 TFY=201. TFZ=36.0 LNU=1260
TFX=275.962 TFY=259.11 TFZ=36.0 LNU=1270
TFX=322.962 TFY=259.11 TFZ=36.0 LNU=1280
TFX=369.962 TFY=259.11 TFZ=36. LNU=1290
TFX=416.962 TFY=259.11 TFZ=36. LNU=1300
TFX=448.382 TFY=154. TFZ=36. LNU=1310
TFX=448.382 TFY=201. TFZ=36. LNU=1320
TFX=275.962 TFY=96.46 TFZ=36. LNU=1330
TFX=322.962 TFY=96.46 TFZ=36. LNU=1340
TFX=369.962 TFY=96.46 TFZ=36. LNU=1350
TFX=416.962 TFY=96.46 TFZ=36. LNU=1360

TFX=244. TFY=176. TFZ=179.69 LNU=1370
TFX=218.7 TFY=154.3 TFZ=111.0 LNU=1380
TFX=218.422 TFY=201. TFZ=111.0 LNU=1390
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TFX=322.962 TFY=259.11 TFZ=111.0 LNU=1410
TFX=369.962 TFY=259.11 TFZ=111. LNU=1420
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TFX=448.382 TFY=154. TFZ=111. LNU=1440
TFX=448.382 TFY=201. TFZ=111. LNU=1450
TFX=275.962 TFY=96.46 TFZ=111. LNU=1460
TFX=322.962 TFY=96.46 TFZ=111. LNU=1470
TFX=369.962 TFY=96.46 TFZ=111. LNU=1480
TFX=416.962 TFY=96.46 TFZ=111. LNU=1490
'
TFX=244. TFY=176. TFZ=300. LNU=1500
TFX=218.7 TFY=154.3 TFZ=184.0 LNU=1510
TFX=218.422 TFY=201. TFZ=184.0 LNU=1520
TFX=275.962 TFY=259.11 TFZ=184.0 LNU=1530
TFX=322.962 TFY=259.11 TFZ=184.0 LNU=1540
TFX=369.962 TFY=259.11 TFZ=184. LNU=1550
TFX=416.962 TFY=259.11 TFZ=184. LNU=1560
TFX=448.382 TFY=154. TFZ=184. LNU=1570
TFX=448.382 TFY=201. TFZ=184. LNU=1580
TFX=275.962 TFY=96.46 TFZ=184. LNU=1590
TFX=322.962 TFY=96.46 TFZ=184. LNU=1600
TFX=369.962 TFY=96.46 TFZ=184. LNU=1610
TFX=416.962 TFY=96.46 TFZ=184. LNU=1620

TFX=91.4 TFY=56. TFZ=420. LNU=1630
TFX=91.4 TFY=312. TFZ=420. LNU=1640
TFX=-62 TFY=176. TFZ=420. LNU=1650
TFX=244. TFY=176. TFZ=420. LNU=1660

END START
END DATA
END
```

ATTACHMENT 3

KENO Input for CASE TN05

Case TN05 was the worst combination of 30x30x30 PSR06 and PSR18 containers that could be modeled. The other cases included some parts of this case. All other cases are on a CD entitled 'NCSE-007'

The subject case description:
3 tiers drums/ 4 tiers 30x30x30/ Center (3 tiers of
2 normal PSR18 drums. Four arrays of 4 30x30x30 PSR06 boxes
with 200gPu-239 spheres tightly packed surrounded by normal PSR18 drums)
2 moderated PSR18 drums touching outside of array

```
=csas25    parm=size=2000000
THREE TIERS - 4 ARRAYS - 8 PSR18 DRUMS SURROUNDING
30X30 BOX - TN05
'NO PSR18 MODERATED DRUMS
'1921 Fuel Rods per 30gal DRUM'
'1/3 RODS FILLED WITH UO2 5VOL%WATER'
'2/3 RODS FILLED WITH 5VOL% WATER'
'200g Pu-239 in SPHERE in 30X30 BOX
27groupndf4 infhommedium
PUO2 1 .95 293 94239 100. END
H2O 1 .05 END
UO2 5 .95 293 92235 5 92238 95 END
H2O 5 .05 END
'OPTIMIZED MOIST AIR SURROUNDING ALL DRUMS
H2O 2 .2 END
'AIR IN PSR18 DRUMS
H2O 6 .05 END
'AIR
H2O 3 .001 END
REG-CONCRETE 4 1.0 END
SS304 7 1. END
H2O 8 .00129 END
H2O 9 1.0 END
'AIR IN 30X30 BOX
H2O 10 .05 END
END COMP
THREE TIERS - 4 ARRAYS - 8 PSR18 DRUMS SURROUNDING
30X30 BOX - TN05
READ PARAM NB8=400 GEN=200 NPG=1210 TBA=5
 NSK=30 NUB=YES END PARAM
READ GEOM
UNIT 1
'CUBOID 1 1 100. 0. .002094 0. 100. 0.
SPHERE 1 1 1.71 ORIGIN 0. 0. 0.
'B25 BOX
UNIT 3
CUBOID 10 1 76.835 .635 76.835 .635 76.835 .635
HOLE 1 38.7 38.7 38.7
CUBOID 7 1 77.47 0. 77.47 0. 77.47 0.
'FUEL ROD WITH UO2

UNIT 4
ZCYLINDER   5  1  .3785  72.3 0. ORIGIN 0. 0.
ZCYLINDER   7  1  .4318  72.3 0. ORIGIN 0. 0.
'FUEL ROD WITH H2O (RHO=0.05)
UNIT 16
ZCYLINDER   6  1  .3785  72.3 0. ORIGIN 0. 0.
ZCYLINDER   7  1  .4318  72.3 0. ORIGIN 0. 0.
'FUEL ROD WITH 100% H2O
UNIT 17
ZCYLINDER   9  1  .3785  72.3 0. ORIGIN 0. 0.
ZCYLINDER   7  1  .4318  72.3 0. ORIGIN 0. 0.

UNIT 23
CUBOID 10 1 76.835 .635 76.835 .635 76.835 .635
HOLE 1 38.7 38.7 38.7
CUBOID 7 1 77.47 0. 77.47 0. 77.47 0.

UNIT 24
CUBOID 10 1 76.835 .635 76.835 .635 76.835 .635
HOLE 1 38.7 38.7 38.7
CUBOID 7 1 77.47 0. 77.47 0. 77.47 0.



UNIT 5
CUBOID 6 1 4.8 -4.8 4.8 -4.8 72.4 0.
HOLE 4 0. 0. 0.
HOLE 16 .8666 0. 0.
HOLE 16 1.7332 0. 0.
HOLE 4 2.5998 0. 0.
HOLE 16 3.4664 0. 0.
HOLE 16 4.3334 0. 0.
HOLE 4 -.8666 0. 0.
HOLE 16 -1.7332 0. 0.
HOLE 16 -2.5998 0. 0.
HOLE 4 -3.4664 0. 0.
HOLE 16 -4.3334 0. 0.
HOLE 16 0. .8666 0.
HOLE 4 0. 1.7332 0.
HOLE 16 0. 2.5998 0.
HOLE 16 0. 3.4664 0.
HOLE 4 0. 4.3334 0.
HOLE 16 0. -.8666 0.
HOLE 16 0. -1.7332 0.
HOLE 4 0. -2.5998 0.
HOLE 16 0. -3.4664 0.
HOLE 16 0. -4.3334 0.
HOLE 4 .8666 .8666 0.
HOLE 16 -.8666 .8666 0.
HOLE 16 .8666 -.8666 0.
HOLE 4 -.8666 -.8666 0.
HOLE 16 1.7332 1.7332 0.
HOLE 16 -1.7332 1.7332 0.
HOLE 4 1.7332 -1.7332 0.
HOLE 16 -1.7332 -1.7332 0.
HOLE 16 2.5998 2.5998 0.
HOLE 4 -2.5998 2.5998 0.
HOLE 16 2.5998 -2.5998 0.
HOLE 16 -2.5998 -2.5998 0.
HOLE 4 3.4664 3.4664 0.
HOLE 16 -3.4664 3.4664 0.
HOLE 16 3.4664 -3.4664 0.
HOLE 4 -3.4664 -3.4664 0.
HOLE 16 4.3334 4.3334 0.
HOLE 16 -4.3334 4.3334 0.
HOLE 4 4.3334 -4.3334 0.
HOLE 16 -4.3334 -4.3334 0.
HOLE 16 .8666 1.7332 0.
HOLE 4 -.8666 1.7332 0.
HOLE 16 .8666 -1.7332 0.
HOLE 16 -.8666 -1.7332 0.
HOLE 4 .8666 2.5998 0.
HOLE 16 -.8666 2.5998 0.
HOLE 16 .8666 -2.5998 0.
HOLE 4 -.8666 -2.5998 0.
HOLE 16 .8666 3.4664 0.
HOLE 16 -.8666 3.4664 0.
HOLE 4 .8666 -3.4664 0.
HOLE 16 -.8666 -3.4664 0.
HOLE 16 .8666 4.3334 0.
HOLE 4 -.8666 4.3334 0.
HOLE 16 .8666 -4.3334 0.
HOLE 16 -.8666 -4.3334 0.
HOLE 4 1.7332 .8666 0.
HOLE 16 -1.7332 .8666 0.
HOLE 16 1.7332 -.8666 0.
HOLE 4 -1.7332 -.8666 0.
HOLE 16 2.5998 .8666 0.
HOLE 16 -2.5998 .8666 0.
HOLE 4 2.5998 -.8666 0.
HOLE 16 -2.5998 -.8666 0.
HOLE 16 3.4664 .8666 0.
HOLE 4 -3.4664 .8666 0.
HOLE 16 3.4664 -.8666 0.
HOLE 16 -3.4664 -.8666 0.
HOLE 4 4.3334 .8666 0.
HOLE 16 -4.3334 .8666 0.
HOLE 16 4.3334 -.8666 0.
HOLE 4 -4.3334 -.8666 0.
HOLE 16 1.7332 2.5998 0.
HOLE 16 -1.7332 2.5998 0.
HOLE 4 1.7332 -2.5998 0.
HOLE 16 -1.7332 -2.5998 0.
HOLE 16 1.7332 3.4664 0.
HOLE 4 -1.7332 3.4664 0.
HOLE 16 1.7332 -3.4664 0.
HOLE 16 -1.7332 -3.4664 0.
HOLE 4 1.7332 4.3334 0.
HOLE 16 -1.7332 4.3334 0.
HOLE 16 1.7332 -4.3334 0.
HOLE 4 -1.7332 -4.3334 0.
HOLE 16 2.5998 3.4664 0.
HOLE 16 -2.5998 3.4664 0.
HOLE 4 2.5998 -3.4664 0.
HOLE 16 -2.5998 -3.4664 0.
HOLE 16 3.4664 4.3334 0.
HOLE 4 -3.4664 4.3334 0.
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HOLE 16 3.4664 -4.3334 0.
HOLE 16 -3.4664 -4.3334 0.
HOLE 4 2.5998 1.7332 0.
HOLE 16 -2.5998 1.7332 0.
HOLE 16 2.5998 -1.7332 0.
HOLE 4 -2.5998 -1.7332 0.
HOLE 16 3.4664 1.7332 0.
HOLE 16 -3.4664 1.7332 0.
HOLE 4 3.4664 -1.7332 0.
HOLE 16 -3.4664 -1.7332 0.
HOLE 16 4.3334 1.7332 0.
HOLE 4 -4.3334 1.7332 0.
HOLE 16 4.3334 -1.7332 0.
HOLE 16 -4.3334 -1.7332 0.
HOLE 4 3.4664 2.5998 0.
HOLE 16 -3.4664 2.5998 0.
HOLE 16 3.4664 -2.5998 0.
HOLE 4 -3.4664 -2.5998 0.
HOLE 16 4.3334 2.5998 0.
HOLE 16 -4.3334 2.5998 0.
HOLE 4 4.3334 -2.5998 0.
HOLE 16 -4.3334 -2.5998 0.
HOLE 16 4.3334 3.4664 0.
HOLE 4 -4.3334 3.4664 0.
HOLE 16 4.3334 -3.4664 0.
HOLE 16 -4.3334 -3.4664 0.
HOLE 4 2.5998 4.3334 0.
HOLE 16 -2.5998 4.3334 0.
HOLE 16 2.5998 -4.3334 0.
HOLE 4 -2.5998 -4.3334 0.

UNIT 11
CUBOID 6 1 2.167 -2.167 2.167 -2.167 72.4 0.
UNIT 9
CUBOID 6 1 2.167 -2.167 2.167 -2.167 72.4 0.
HOLE 4 0. 0. 0.
HOLE 16 .8666 0. 0.
HOLE 16 1.7332 0. 0.
HOLE 4 -.8666 0. 0.
HOLE 16 -1.7332 0. 0.
HOLE 16 0. .8666 0.
HOLE 4 0. 1.7332 0.
HOLE 16 0. -.8666 0.
HOLE 16 0. -1.7332 0.
HOLE 4 .8666 .8666 0.
HOLE 16 -.8666 .8666 0.
HOLE 16 .8666 -.8666 0.
HOLE 4 -.8666 -.8666 0.
HOLE 16 1.7332 1.7332 0.
HOLE 16 -1.7332 1.7332 0.
HOLE 4 1.7332 -1.7332 0.
HOLE 16 -1.7332 -1.7332 0.
HOLE 16 .8666 1.7332 0.
HOLE 4 -.8666 1.7332 0.
HOLE 16 .8666 -1.7332 0.
HOLE 16 -.8666 -1.7332 0.
HOLE 4 1.7332 .8666 0.
HOLE 16 -1.7332 .8666 0.
HOLE 16 1.7332 -.8666 0.
HOLE 4 -1.7332 -.8666 0.
UNIT 13
CUBOID 6 1 2.167 -2.167 1.3029 -2.1715 72.4 0.
UNIT 12
CUBOID 6 1 2.167 -2.167 1.3029 -2.1715 72.4 0.
HOLE 4 0. 0. 0.
HOLE 16 .8666 0. 0.
HOLE 16 1.7332 0. 0.
HOLE 4 -.8666 0. 0.
HOLE 16 -1.7332 0. 0.
HOLE 16 0. .8666 0.
HOLE 4 0. -.8666 0.
HOLE 16 0. -1.7332 0.
HOLE 16 .8666 .8666 0.
HOLE 4 -.8666 .8666 0.
HOLE 16 .8666 -.8666 0.
HOLE 16 -.8666 -.8666 0.
HOLE 4 1.7332 -1.7332 0.
HOLE 16 -1.7332 -1.7332 0.
HOLE 16 .8666 -1.7332 0.
HOLE 4 -.8666 -1.7332 0.
HOLE 16 1.7332 .8666 0.
HOLE 16 -1.7332 .8666 0.
HOLE 4 1.7332 -.8666 0.
HOLE 16 -1.7332 -.8666 0.
UNIT 14
CUBOID 6 1 1.3029 -2.1715 2.167 -2.167 72.4 0.
UNIT 15
CUBOID 6 1 1.3029 -2.1715 2.167 -2.167 72.4 0.
HOLE 4 0. 0. 0.
HOLE 16 .8666 0. 0.
HOLE 16 -.8666 0. 0.
HOLE 4 -1.7332 0. 0.
HOLE 16 0. .8666 0.
HOLE 16 0. 1.7332 0.
HOLE 4 0. -.8666 0.
HOLE 16 0. -1.7332 0.
HOLE 16 .8666 .8666 0.
HOLE 4 -.8666 .8666 0.
HOLE 16 .8666 -.8666 0.
HOLE 16 -.8666 -.8666 0.
HOLE 4 -1.7332 1.7332 0.
HOLE 16 -1.7332 -1.7332 0.
HOLE 16 .8666 1.7332 0.
HOLE 4 -.8666 1.7332 0.
HOLE 16 .8666 -1.7332 0.
HOLE 16 -.8666 -1.7332 0.
HOLE 4 -1.7332 .8666 0.
HOLE 16 -1.7332 -.8666 0.
'CONCRETE FLOOR
UNIT 6
CUBOID 4 1 292.5 -209. 359. -64. 91.44 0.
'30 GAL DRUM
UNIT 7
ZCYLINDER   6   1   23.04  73.025 0. ORIGIN 0.0 0.0
HOLE 4 0. 19.3132 0.
HOLE 16 0. 20.1919 0.
HOLE 16 0 21.0706 0.
HOLE 4 0. 21.9493 0.
HOLE 16 0. -19.3132 0.
HOLE 16 0. -20.1919 0.
HOLE 4 0. -21.0706 0.
HOLE 16 0. -21.9493 0.
HOLE 16 19.3132 0. 0.
HOLE 4 20.1919 0. 0.
HOLE 16 21.0706 0. 0.
HOLE 16 21.9493 0. 0.
HOLE 4 -19.3132 0. 0.
HOLE 16 -20.1919 0. 0.
HOLE 16 -21.0706 0. 0.
HOLE 4 -21.9493 0. 0.   com= '+++'
HOLE 16 .8 19.7522 0.    com= '—'
HOLE 16 .8 20.6309 0.
HOLE 4 .8 21.5096 0.
HOLE 16 .8 22.3883 0.
HOLE 16 1.6 19.3132 0.
HOLE 4 1.6 20.1919 0.
HOLE 16 1.6 21.0706 0.
HOLE 16 1.6 21.9493 0.
HOLE 4 2.4 19.7522 0.
HOLE 16 2.4 20.6309 0.
HOLE 16 2.4 21.5096 0.
HOLE 4 3.2 19.3132 0.
HOLE 16 3.2 20.1919 0.
HOLE 16 3.2 21.0706 0.
HOLE 4 4. 19.7522 0.
HOLE 16 4. 20.6309 0.
HOLE 16 4. 21.5096 0.
HOLE 4 4.8 19.3132 0.
HOLE 16 4.8 20.1919 0.
HOLE 16 4.8 21.0706 0.
HOLE 4 5.6 19.7522 0.
HOLE 16 5.6 20.6309 0.
HOLE 16 6.4 19.3132 0.
HOLE 4 6.4 20.1919 0.
HOLE 16 7.2 19.7522 0.
HOLE 16 7.2 20.6309 0.
HOLE 4 8.0 19.3132 0.
HOLE 16 8.0 20.1919 0.
```

```
HOLE 16 8.8 19.7522 0.
HOLE 4 9.6 19.3132 0.
HOLE 16 10.4 19.7522 0.
HOLE 16 11.2 19.3132 0.  com='+++'
HOLE 4 .8 -19.7522 0.  com='—'
HOLE 16 .8 -20.6309 0.
HOLE 16 .8 -21.5096 0.
HOLE 4 .8 -22.3883 0.
HOLE 16 1.6 -19.3132 0.
HOLE 16 1.6 -20.1919 0.
HOLE 4 1.6 -21.0706 0.
HOLE 16 1.6 -21.9493 0.
HOLE 16 2.4 -19.7522 0.
HOLE 4 2.4 -20.6309 0.
HOLE 16 2.4 -21.5096 0.
HOLE 16 3.2 -19.3132 0.
HOLE 4 3.2 -20.1919 0.
HOLE 16 3.2 -21.0706 0.
HOLE 16 4. -19.7522 0.
HOLE 4 4. -20.6309 0.
HOLE 16 4. -21.5096 0.
HOLE 16 4.8 -19.3132 0.
HOLE 4 4.8 -20.1919 0.
HOLE 16 4.8 -21.0706 0.
HOLE 16 5.6 -19.7522 0.
HOLE 4 5.6 -20.6309 0.
HOLE 16 6.4 -19.3132 0.
HOLE 16 6.4 -20.1919 0.
HOLE 4 7.2 -19.7522 0.
HOLE 16 7.2 -20.6309 0.
HOLE 16 8.0 -19.3132 0.
HOLE 4 8.0 -20.1919 0.
HOLE 16 8.8 -19.7522 0.
HOLE 16 9.6 -19.3132 0.
HOLE 4 10.4 -19.7522 0.
HOLE 16 11.2 -19.3132 0. com='—'

HOLE 16 -.8 19.7522 0. com='++++'
HOLE 4 -.8 20.6309 0.
HOLE 16 -.8 21.5096 0.
HOLE 16 -.8 22.3883 0.
HOLE 4 -1.6 19.3132 0.
HOLE 16 -1.6 20.1919 0.
HOLE 16 -1.6 21.0706 0.
HOLE 4 -1.6 21.9493 0.
HOLE 16 -2.4 19.7522 0.
HOLE 16 -2.4 20.6309 0.
HOLE 4 -2.4 21.5096 0.
HOLE 16 -3.2 19.3132 0.
HOLE 16 -3.2 20.1919 0.
HOLE 4 -3.2 21.0706 0.
HOLE 16 -4. 19.7522 0.
HOLE 16 -4. 20.6309 0.
HOLE 4 -4. 21.5096 0.
HOLE 16 -4.8 19.3132 0.
HOLE 16 -4.8 20.1919 0.
HOLE 4 -4.8 21.0706 0.
HOLE 16 -5.6 19.7522 0.
HOLE 16 -5.6 20.6309 0.
HOLE 4 -6.4 19.3132 0.
HOLE 16 -6.4 20.1919 0.
HOLE 16 -7.2 19.7522 0.
HOLE 4 -7.2 20.6309 0.
HOLE 16 -8.0 19.3132 0.
HOLE 16 -8.0 20.1919 0.
HOLE 4 -8.8 19.7522 0.
HOLE 16 -9.6 19.3132 0.
HOLE 16 -10.4 19.7522 0.
HOLE 4 -11.2 19.3132 0. com='—'
HOLE 16 -.8 -19.7522 0. com='++++'
HOLE 16 -.8 -20.6309 0.
HOLE 4 -.8 -21.5096 0.
HOLE 16 -.8 -22.3883 0.
HOLE 16 -1.6 -19.3132 0.
HOLE 4 -1.6 -20.1919 0.
HOLE 16 -1.6 -21.0706 0.
HOLE 16 -1.6 -21.9493 0.
HOLE 4 -2.4 -19.7522 0.
HOLE 16 -2.4 -20.6309 0.
HOLE 16 -2.4 -21.5096 0.
HOLE 4 -3.2 -19.3132 0.
HOLE 16 -3.2 -20.1919 0.
HOLE 16 -3.2 -21.0706 0.
HOLE 4 -4. -19.7522 0.
HOLE 16 -4. -20.6309 0.
HOLE 16 -4. -21.5096 0.
HOLE 4 -4.8 -19.3132 0.
HOLE 16 -4.8 -20.1919 0.
HOLE 16 -4.8 -21.0706 0.
HOLE 4 -5.6 -19.7522 0.
HOLE 16 -5.6 -20.6309 0.
HOLE 16 -6.4 -19.3132 0.
HOLE 4 -6.4 -20.1919 0.
HOLE 16 -7.2 -19.7522 0.
HOLE 16 -7.2 -20.6309 0.
HOLE 4 -8.0 -19.3132 0.
HOLE 16 -8.0 -20.1919 0.
HOLE 16 -8.8 -19.7522 0.
HOLE 4 -9.6 -19.3132 0.
HOLE 16 -10.4 -19.7522 0.
HOLE 16 -11.2 -19.3132 0.

HOLE 4 19.7522 .8  0. com='++++'
HOLE 16 20.6309 .8  0.
HOLE 16 21.5096 .8  0
HOLE 4 22.3883 .8  0.
HOLE 16  19.3132 1.6  0.
HOLE 16  20.1919 1.6 0.
HOLE 4  21.0706 1.6 0.
HOLE 16  21.9493 1.6 0.
HOLE 16 19.7522 2.4 0.
HOLE 4 20.6309 2.4 0.
HOLE 16 21.5096 2.4 0.
HOLE 16 19.3132 3.2 0.
HOLE 4 20.1919 3.2 0.
HOLE 16 21.0706 3.2 0.
HOLE 16 19.7522 4. 0.
HOLE 4 20.6309 4. 0.
HOLE 16 21.5096 4. 0.
HOLE 16 19.3132 4.8 0.
HOLE 4 20.1919 4.8 0.
HOLE 16 21.0706 4.8 0.
HOLE 16 19.7522 5.6 0.
HOLE 4 20.6309 5.6 0.
HOLE 16 19.3132 6.4 0.
HOLE 16 20.1919 6.4 0.
HOLE 4 19.7522 7.2 0.
HOLE 16 20.6309 7.2 0.
HOLE 16 19.3132 8.0 0.
HOLE 4 20.1919 8.0 0.
HOLE 16 19.7522 8.8 0.
HOLE 16 19.3132 9.6 0.
HOLE 4 19.7522 10.4 0.
HOLE 16 19.3132 11.2 0. com='----'
HOLE 16 -19.7522 .8 0. com='++++'
HOLE 4 -20.6309 .8 0.
HOLE 16 -21.5096 .8 0.
HOLE 16 -22.3883 .8 0.
HOLE 4 -19.3132 1.6 0.
HOLE 16 -20.1919 1.6 0.
HOLE 16 -21.0706 1.6 0.
HOLE 4 -21.9493 1.6 0.
HOLE 16 -19.7522 2.4 0.
HOLE 16 -20.6309 2.4 0.
HOLE 4 -21.5096 2.4 0.
HOLE 16 -19.3132 3.2 0.
HOLE 16 -20.1919 3.2 0.
HOLE 4 -21.0706 3.2 0.
HOLE 16 -19.7522 4. 0.
HOLE 16 -20.6309 4. 0.
HOLE 4 -21.5096 4. 0.
HOLE 16 -19.3132 4.8 0.
HOLE 16 -20.1919 4.8 0.
HOLE 4 -21.0706 4.8 0.
HOLE 16 -19.7522 5.6 0.
HOLE 16 -20.6309 5.6 0.
HOLE 4 -19.3132 6.4 0.
HOLE 16 -20.1919 6.4 0.
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HOLE 16 -19.7522 7.2 0.
HOLE 4 -20.6309 7.2 0.
HOLE 16 -19.3132 8.0 0.
HOLE 16 -20.1919 8.0 0.
HOLE 4 -19.7522 8.8 0.
HOLE 16 -19.3132 9.6 0.
HOLE 16 -19.7522 10.4 0.
HOLE 4 -19.3132 11.2 0. com='--'

HOLE 16 19.7522 -.8 0. com='++++'
HOLE 16 20.6309 -.8 0.
HOLE 4 21.5096 -.8 0.
HOLE 16 22.3883 -.8 0.
HOLE 16 19.3132 -1.6 0.
HOLE 4 20.1919 -1.6 0.
HOLE 16 21.0706 -1.6 0.
HOLE 16 21.9493 -1.6 0.
HOLE 4 19.7522 -2.4 0.
HOLE 16 20.6309 -2.4 0.
HOLE 16 21.5096 -2.4 0.
HOLE 4 19.3132 -3.2 0.
HOLE 16 20.1919 -3.2 0.
HOLE 16 21.0706 -3.2 0.
HOLE 4 19.7522 -4. 0.
HOLE 16 20.6309 -4. 0.
HOLE 16 21.5096 -4. 0.
HOLE 4 19.3132 -4.8 0.
HOLE 16 20.1919 -4.8 0.
HOLE 16 21.0706 -4.8 0.
HOLE 4 19.7522 -5.6 0.
HOLE 16 20.6309 -5.6 0.
HOLE 16 19.3132 -6.4 0.
HOLE 4 20.1919 -6.4 0.
HOLE 16 19.7522 -7.2 0.
HOLE 16 20.6309 -7.2 0.
HOLE 4 19.3132 -8.0 0.
HOLE 16 20.1919 -8.0 0.
HOLE 16 19.7522 -8.8 0.
HOLE 4 19.3132 -9.6 0.
HOLE 16 19.7522 -10.4 0.
HOLE 16 19.3132 -11.2 0. com='---'
HOLE 4 -19.7522 -.8 0. com='++++'
HOLE 16 -20.6309 -.8 0.
HOLE 16 -21.5096 -.8 0.
HOLE 4 -22.3883 -.8 0.
HOLE 16 -19.3132 -1.6 0.
HOLE 16 -20.1919 -1.6 0.
HOLE 4 -21.0706 -1.6 0.
HOLE 16 -21.9493 -1.6 0.
HOLE 16 -19.7522 -2.4 0.
HOLE 4 -20.6309 -2.4 0.
HOLE 16 -21.5096 -2.4 0.
HOLE 16 -19.3132 -3.2 0.
HOLE 4 -20.1919 -3.2 0.
HOLE 16 -21.0706 -3.2 0.
HOLE 16 -19.7522 -4. 0.
HOLE 4 -20.6309 -4. 0.
HOLE 16 -21.5096 -4. 0.
HOLE 16 -19.3132 -4.8 0.
HOLE 4 -20.1919 -4.8 0.
HOLE 16 -21.0706 -4.8 0.
HOLE 16 -19.7522 -5.6 0.
HOLE 4 -20.6309 -5.6 0.
HOLE 16 -19.3132 -6.4 0.
HOLE 16 -20.1919 -6.4 0.
HOLE 4 -19.7522 -7.2 0.
HOLE 16 -20.6309 -7.2 0.
HOLE 16 -19.3132 -8.0 0.
HOLE 4 -20.1919 -8.0 0.
HOLE 16 -19.7522 -8.8 0.
HOLE 16 -19.3132 -9.6 0.
HOLE 4 -19.7522 -10.4 0.
HOLE 16 -19.3132 -11.2 0.

HOLE 5 0. 0. 0.
HOLE 5 9.7 0. 0.
HOLE 5 0. 9.7 0.
HOLE 5 -9.7 0. 0.
HOLE 9 2.17 16.7 0.
HOLE 9 -2.17 16.7 0.
HOLE 9 6.52 16.7 0.
HOLE 9 -6.52 16.7 0.
HOLE 9 2.17 -16.7 0.
HOLE 9 -2.17 -16.7 0.
HOLE 9 6.52 -16.7 0.
HOLE 9 -6.52 -16.7 0.
HOLE 9  16.7 2.17 0.
HOLE 9  16.7 -2.17 0.
HOLE 9 16.7 6.52 0.
HOLE 9  16.7 -6.52 0.
HOLE 9 -16.7 2.17  0.
HOLE 9 -16.7 -2.17  0.
HOLE 9 -16.7 6.52 0.
HOLE 9 -16.7 -6.52  0.
HOLE 12 -16.7 10.86  0.
HOLE 12 16.7 -9.9914  0.
HOLE 12 16.7 10.86  0.
HOLE 12 -16.7 -9.9914  0.
HOLE 15 10.86 -16.7  0.
HOLE 15 -9.9914 16.7  0.
HOLE 15 10.86 16.7  0.
HOLE 15  -9.9914  -16.7 0.

HOLE 5 0. -9.7 0.
HOLE 5 9.7 9.7 0.
HOLE 5 -9.7 9.7 0.
HOLE 5 9.7 -9.7 0.
HOLE 5 -9.7 -9.7 0.


UNIT 18
CUBOID 6 1 4.8 -4.8 4.8 -4.8  72.4 0.
HOLE 4  0. 0. 0.
HOLE 17  .8666   0.  0.
HOLE 17  1.7332  0.  0.
HOLE 4  2.5998  0.  0.
HOLE 17  3.4664  0.  0.
HOLE 17  4.3334   0.  0.
HOLE 4  -.8666   0.  0.
HOLE 17  -1.7332  0.  0.
HOLE 17  -2.5998  0.  0.
HOLE 4  -3.4664  0.  0.
HOLE 17  -4.3334   0.  0.
HOLE 17  0. .8666   0.
HOLE 4  0. 1.7332  0.
HOLE 17  0. 2.5998  0.
HOLE 17  0. 3.4664  0.
HOLE 4  0. 4.3334   0.
HOLE 17  0. -.8666   0.
HOLE 17  0. -1.7332  0.
HOLE 4  0. -2.5998  0.
HOLE 17  0. -3.4664  0.
HOLE 17  0. -4.3334   0.
HOLE 4  .8666 .8666  0.
HOLE 17  -.8666 .8666  0.
HOLE 17  .8666 -.8666  0.
HOLE 4  -.8666 -.8666  0.
HOLE 17  1.7332 1.7332  0.
HOLE 17  -1.7332 1.7332  0.
HOLE 4  1.7332 -1.7332  0.
HOLE 17  -1.7332 -1.7332  0.
HOLE 17  2.5998 2.5998 0.
HOLE 4  -2.5998 2.5998 0.
HOLE 17  2.5998 -2.5998 0.
HOLE 17  -2.5998 -2.5998 0.
HOLE 4  3.4664 3.4664 0.
HOLE 17  -3.4664 3.4664 0.
HOLE 17  3.4664 -3.4664 0.
HOLE 4  -3.4664 -3.4664 0.
HOLE 17  4.3334  4.3334  0.
HOLE 17  -4.3334  4.3334  0.
HOLE 4  4.3334  -4.3334  0.
HOLE 17  -4.3334  -4.3334  0.
HOLE 17 .8666 1.7332  0.
HOLE 4 -.8666 1.7332  0.
HOLE 17 .8666 -1.7332  0.
HOLE 17 -.8666 -1.7332  0.
HOLE 4 .8666 2.5998 0.
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```
HOLE 17 -.8666 2.5998 0.
HOLE 17 .8666 -2.5998 0.
HOLE 4 -.8666 -2.5998 0.
HOLE 17 .8666 3.4664 0.
HOLE 17 -.8666 3.4664 0.
HOLE 4 .8666 -3.4664 0.
HOLE 17 -.8666 -3.4664 0.
HOLE 17 .8666 4.3334 0.
HOLE 4 -.8666 4.3334 0.
HOLE 17 .8666 -4.3334 0.
HOLE 17 -.8666 -4.3334 0.
HOLE 4 1.7332 .8666 0.
HOLE 17 -1.7332 .8666 0.
HOLE 17 1.7332 -.8666 0.
HOLE 4 -1.7332 -.8666 0.
HOLE 17 2.5998 .8666 0.
HOLE 17 -2.5998 .8666 0.
HOLE 4 2.5998 -.8666 0.
HOLE 17 -2.5998 -.8666 0.
HOLE 17 3.4664 .8666 0.
HOLE 4 -3.4664 .8666 0.
HOLE 17 3.4664 -.8666 0.
HOLE 17 -3.4664 -.8666 0.
HOLE 4 4.3334 .8666 0.
HOLE 17 -4.3334 .8666 0.
HOLE 17 4.3334 -.8666 0.
HOLE 4 -4.3334 -.8666 0.
HOLE 17 1.7332 2.5998 0.
HOLE 17 -1.7332 2.5998 0.
HOLE 4 1.7332 -2.5998 0.
HOLE 17 -1.7332 -2.5998 0.
HOLE 17 1.7332 3.4664 0.
HOLE 4 -1.7332 3.4664 0.
HOLE 17 1.7332 -3.4664 0.
HOLE 17 -1.7332 -3.4664 0.
HOLE 4 1.7332 4.3334 0.
HOLE 17 -1.7332 4.3334 0.
HOLE 17 1.7332 -4.3334 0.
HOLE 4 -1.7332 -4.3334 0.
HOLE 17 2.5998 3.4664 0.
HOLE 17 -2.5998 3.4664 0.
HOLE 4 2.5998 -3.4664 0.
HOLE 17 -2.5998 -3.4664 0.
HOLE 17 3.4664 4.3334 0.
HOLE 4 -3.4664 4.3334 0.
HOLE 17 3.4664 -4.3334 0.
HOLE 17 -3.4664 -4.3334 0.
HOLE 4 2.5998 1.7332 0.
HOLE 17 -2.5998 1.7332 0.
HOLE 17 2.5998 -1.7332 0.
HOLE 4 -2.5998 -1.7332 0.
HOLE 17 3.4664 1.7332 0.
HOLE 17 -3.4664 1.7332 0.
HOLE 4 3.4664 -1.7332 0.
HOLE 17 -3.4664 -1.7332 0.
HOLE 17 4.3334 1.7332 0.
HOLE 4 -4.3334 1.7332 0.
HOLE 17 4.3334 -1.7332 0.
HOLE 17 -4.3334 -1.7332 0.
HOLE 4 3.4664 2.5998 0.
HOLE 17 -3.4664 2.5998 0.
HOLE 17 3.4664 -2.5998 0.
HOLE 4 -3.4664 -2.5998 0.
HOLE 17 4.3334 2.5998 0.
HOLE 17 -4.3334 2.5998 0.
HOLE 4 4.3334 -2.5998 0.
HOLE 17 -4.3334 -2.5998 0.
HOLE 17 4.3334 3.4664 0.
HOLE 4 -4.3334 3.4664 0.
HOLE 17 4.3334 -3.4664 0.
HOLE 17 -4.3334 -3.4664 0.
HOLE 4 2.5998 4.3334 0.
HOLE 17 -2.5998 4.3334 0.
HOLE 17 2.5998 -4.3334 0.
HOLE 4 -2.5998 -4.3334 0.

UNIT 19
CUBOID 6 1 2.167 -2.167 2.167 -2.167 72.4 0.
HOLE 4 0. 0. 0.
HOLE 17 .8666 0. 0.
HOLE 17 1.7332 0. 0.
HOLE 4 -.8666 0. 0.
HOLE 17 -1.7332 0. 0.
HOLE 17 0. .8666 0.
HOLE 4 0. 1.7332 0.
HOLE 17 0. -.8666 0.
HOLE 17 0. -1.7332 0.
HOLE 4 .8666 .8666 0.
HOLE 17 -.8666 .8666 0.
HOLE 17 .8666 -.8666 0.
HOLE 4 -.8666 -.8666 0.
HOLE 17 1.7332 1.7332 0.
HOLE 17 -1.7332 1.7332 0.
HOLE 4 1.7332 -1.7332 0.
HOLE 17 -1.7332 -1.7332 0.
HOLE 17 .8666 1.7332 0.
HOLE 4 -.8666 1.7332 0.
HOLE 17 .8666 -1.7332 0.
HOLE 17 -.8666 -1.7332 0.
HOLE 4 1.7332 .8666 0.
HOLE 17 -1.7332 .8666 0.
HOLE 17 1.7332 -.8666 0.
HOLE 4 -1.7332 -.8666 0.
UNIT 20
CUBOID 6 1 2.167 -2.167 1.3029 -2.1715 72.4 0.
HOLE 4 0. 0. 0.
HOLE 17 .8666 0. 0.
HOLE 17 1.7332 0. 0.
HOLE 4 -.8666 0. 0.
HOLE 17 -1.7332 0. 0.
HOLE 17 0. .8666 0.
HOLE 4 0. -.8666 0.
HOLE 17 0. -1.7332 0.
HOLE 17 .8666 .8666 0.
HOLE 4 -.8666 .8666 0.
HOLE 17 .8666 -.8666 0.
HOLE 17 -.8666 -.8666 0.
HOLE 4 1.7332 -1.7332 0.
HOLE 17 -1.7332 -1.7332 0.
HOLE 17 .8666 -1.7332 0.
HOLE 4 -.8666 -1.7332 0.
HOLE 17 1.7332 .8666 0.
HOLE 17 -1.7332 .8666 0.
HOLE 4 1.7332 -.8666 0.
HOLE 17 -1.7332 -.8666 0.
UNIT 21
CUBOID 6 1 1.3029 -2.1715 2.167 -2.167 72.4 0.
HOLE 4 0. 0. 0.
HOLE 17 .8666 0. 0.
HOLE 17 -.8666 0. 0.
HOLE 4 -1.7332 0. 0.
HOLE 17 0. .8666 0.
HOLE 17 0. 1.7332 0.
HOLE 4 0. -.8666 0.
HOLE 17 0. -1.7332 0.
HOLE 17 .8666 .8666 0.
HOLE 4 -.8666 .8666 0.
HOLE 17 .8666 -.8666 0.
HOLE 17 -.8666 -.8666 0.
HOLE 4 -1.7332 1.7332 0.
HOLE 17 -1.7332 -1.7332 0.
HOLE 17 .8666 1.7332 0.
HOLE 4 -.8666 1.7332 0.
HOLE 17 .8666 -1.7332 0.
HOLE 17 -.8666 -1.7332 0.
HOLE 4 -1.7332 .8666 0.
HOLE 17 -1.7332 -.8666 0.
'30 GAL DRUM - FULL DENSITY
UNIT 22
ZCYLINDER   6  1  23.04  73.025 0. ORIGIN 0.0 0.0
HOLE 4 0. 19.3132 0.
HOLE 17 0. 20.1919 0.
HOLE 17 0. 21.0706 0.
HOLE 4 0. 21.9493 0.
HOLE 17 0. -19.3132 0.
HOLE 17 0. -20.1919 0.
HOLE 4 0. -21.0706 0
HOLE 17 0. -21.9493 0.
```

```
HOLE 17  19.3132 0.  0.
HOLE 4  20.1919 0.  0.
HOLE 17  21.0706 0.  0.
HOLE 17  21.9493 0.  0.
HOLE 4  -19.3132 0. 0.
HOLE 17  -20.1919 0. 0.
HOLE 17  -21.0706 0. 0.
HOLE 4  -21.9493 0. 0.  com= '+++'
HOLE 17 .8 19.7522 0.    com= '---'
HOLE 17 .8 20.6309 0.
HOLE 4 .8 21.5096 0.
HOLE 17 .8 22.3883 0.
HOLE 17 1.6 19.3132 0.
HOLE 4 1.6 20.1919 0.
HOLE 17 1.6 21.0706 0.
HOLE 17 1.6 21.9493 0.
HOLE 4 2.4 19.7522 0.
HOLE 17 2.4 20.6309 0.
HOLE 17 2.4 21.5096 0.
HOLE 4 3.2 19.3132 0.
HOLE 17 3.2 20.1919 0.
HOLE 17 3.2 21.0706 0.
HOLE 4 4. 19.7522 0.
HOLE 17 4. 20.6309 0.
HOLE 17 4. 21.5096 0.
HOLE 4 4.8 19.3132 0.
HOLE 17 4.8 20.1919 0.
HOLE 17 4.8 21.0706 0.
HOLE 4 5.6 19.7522 0.
HOLE 17 5.6 20.6309 0.
HOLE 17 6.4 19.3132 0.
HOLE 4 6.4 20.1919 0.
HOLE 17 7.2 19.7522 0.
HOLE 17 7.2 20.6309 0.
HOLE 4 8.0 19.3132 0.
HOLE 17 8.0 20.1919 0.
HOLE 17 8.8 19.7522 0.
HOLE 4 9.6 19.3132 0.
HOLE 17 10.4 19.7522 0.
HOLE 17 11.2 19.3132 0.  com='+++'
HOLE 4 .8 -19.7522 0.  com='---'
HOLE 17 .8 -20.6309 0.
HOLE 17 .8 -21.5096 0.
HOLE 4 .8 -22.3883 0.
HOLE 17 1.6 -19.3132 0.
HOLE 17 1.6 -20.1919 0.
HOLE 4 1.6 -21.0706 0.
HOLE 17 1.6 -21.9493 0.
HOLE 17 2.4 -19.7522 0.
HOLE 4 2.4 -20.6309 0.
HOLE 17 2.4 -21.5096 0.
HOLE 17 3.2 -19.3132 0.
HOLE 4 3.2 -20.1919 0.
HOLE 17 3.2 -21.0706 0.
HOLE 17 4. -19.7522 0.
HOLE 4 4. -20.6309 0.
HOLE 17 4. -21.5096 0.
HOLE 17 4.8 -19.3132 0.
HOLE 4 4.8 -20.1919 0.
HOLE 17 4.8 -21.0706 0.
HOLE 17 5.6 -19.7522 0.
HOLE 4 5.6 -20.6309 0.
HOLE 17 6.4 -19.3132 0.
HOLE 17 6.4 -20.1919 0.
HOLE 4 7.2 -19.7522 0.
HOLE 17 7.2 -20.6309 0.
HOLE 17 8.0 -19.3132 0.
HOLE 4 8.0 -20.1919 0.
HOLE 17 8.8 -19.7522 0.
HOLE 17 9.6 -19.3132 0.
HOLE 4 10.4 -19.7522 0.
HOLE 17 11.2 -19.3132 0. com='---'

HOLE 17 -.8 19.7522 0. com='++++'
HOLE 4 -.8 20.6309 0.
HOLE 17 -.8 21.5096 0.
HOLE 17 -.8 22.3883 0.
HOLE 4 -1.6 19.3132 0.
HOLE 17 -1.6 20.1919 0.
HOLE 17 -1.6 21.0706 0.
HOLE 4 -1.6 21.9493 0.
HOLE 17 -2.4 19.7522 0.
HOLE 17 -2.4 20.6309 0.
HOLE 4 -2.4 21.5096 0.
HOLE 17 -3.2 19.3132 0.
HOLE 17 -3.2 20.1919 0.
HOLE 4 -3.2 21.0706 0.
HOLE 17 -4. 19.7522 0.
HOLE 17 -4. 20.6309 0.
HOLE 4 -4. 21.5096 0.
HOLE 17 -4.8 19.3132 0.
HOLE 17 -4.8 20.1919 0.
HOLE 4 -4.8 21.0706 0.
HOLE 17 -5.6 19.7522 0.
HOLE 17 -5.6 20.6309 0.
HOLE 4 -6.4 19.3132 0.
HOLE 17 -6.4 20.1919 0.
HOLE 17 -7.2 19.7522 0.
HOLE 4 -7.2 20.6309 0.
HOLE 17 -8.0 19.3132 0.
HOLE 17 -8.0 20.1919 0.
HOLE 4 -8.8 19.7522 0.
HOLE 17 -9.6 19.3132 0.
HOLE 17 -10.4 19.7522 0.
HOLE 4 -11.2 19.3132 0. com='----'
HOLE 17 -.8 -19.7522 0. com='++++'
HOLE 17 -.8 -20.6309 0.
HOLE 4 -.8 -21.5096 0.
HOLE 17 -.8 -22.3883 0.
HOLE 17 -1.6 -19.3132 0.
HOLE 4 -1.6 -20.1919 0.
HOLE 17 -1.6 -21.0706 0.
HOLE 17 -1.6 -21.9493 0.
HOLE 4 -2.4 -19.7522 0.
HOLE 17 -2.4 -20.6309 0.
HOLE 17 -2.4 -21.5096 0.
HOLE 4 -3.2 -19.3132 0.
HOLE 17 -3.2 -20.1919 0.
HOLE 17 -3.2 -21.0706 0.
HOLE 4 -4. -19.7522 0.
HOLE 17 -4. -20.6309 0.
HOLE 17 -4. -21.5096 0.
HOLE 4 -4.8 -19.3132 0.
HOLE 17 -4.8 -20.1919 0.
HOLE 17 -4.8 -21.0706 0.
HOLE 4 -5.6 -19.7522 0.
HOLE 17 -5.6 -20.6309 0.
HOLE 17 -6.4 -19.3132 0.
HOLE 4 -6.4 -20.1919 0.
HOLE 17 -7.2 -19.7522 0.
HOLE 17 -7.2 -20.6309 0.
HOLE 4 -8.0 -19.3132 0.
HOLE 17 -8.0 -20.1919 0.
HOLE 17 -8.8 -19.7522 0.
HOLE 4 -9.6 -19.3132 0.
HOLE 17 -10.4 -19.7522 0.
HOLE 17 -11.2 -19.3132 0.

HOLE 4 19.7522 .8  0. com='++++'
HOLE 17 20.6309 .8  0.
HOLE 17 21.5096 .8  0.
HOLE 4 22.3883 .8  0.
HOLE 17  19.3132 1.6  0.
HOLE 17  20.1919 1.6 0.
HOLE 4  21.0706 1.6 0.
HOLE 17  21.9493 1.6 0.
HOLE 17 19.7522 2.4 0.
HOLE 4 20.6309 2.4 0.
HOLE 17 21.5096 2.4 0.
HOLE 17 19.3132 3.2 0.
HOLE 4 20.1919 3.2 0.
HOLE 17 21.0706 3.2 0.
HOLE 17 19.7522 4. 0.
HOLE 4 20.6309 4. 0.
HOLE 17 21.5096 4. 0.
HOLE 17 19.3132 4.8 0.
HOLE 4 20.1919 4.8 0.
HOLE 17 21.0706 4.8 0.
```

```
HOLE 17 19.7522 5.6 0.
HOLE 4 20.6309 5.6 0.
HOLE 17 19.3132 6.4 0.
HOLE 17 20.1919 6.4 0.
HOLE 4 19.7522 7.2 0.
HOLE 17 20.6309 7.2 0.
HOLE 17 19.3132 8.0 0.
HOLE 4 20.1919 8.0 0.
HOLE 17 19.7522 8.8 0.
HOLE 17 19.3132 9.6 0.
HOLE 4 19.7522 10.4 0.
HOLE 17 19.3132 11.2 0. com='----'
HOLE 17 -19.7522 .8 0. com='++++'
HOLE 4 -20.6309 .8 0.
HOLE 17 -21.5096 .8 0.
HOLE 17 -22.3883 .8 0.
HOLE 4 -19.3132 1.6 0.
HOLE 17 -20.1919 1.6 0.
HOLE 17 -21.0706 1.6 0.
HOLE 4 -21.9493 1.6 0.
HOLE 17 -19.7522 2.4 0.
HOLE 17 -20.6309 2.4 0.
HOLE 4 -21.5096 2.4 0.
HOLE 17 -19.3132 3.2 0.
HOLE 17 -20.1919 3.2 0.
HOLE 4 -21.0706 3.2 0.
HOLE 17 -19.7522 4. 0.
HOLE 17 -20.6309 4. 0.
HOLE 4 -21.5096 4. 0.
HOLE 17 -19.3132 4.8 0.
HOLE 17 -20.1919 4.8 0.
HOLE 4 -21.0706 4.8 0.
HOLE 17 -19.7522 5.6 0.
HOLE 17 -20.6309 5.6 0.
HOLE 4 -19.3132 6.4 0.
HOLE 17 -20.1919 6.4 0.
HOLE 17 -19.7522 7.2 0.
HOLE 4 -20.6309 7.2 0.
HOLE 17 -19.3132 8.0 0.
HOLE 17 -20.1919 8.0 0.
HOLE 4 -19.7522 8.8 0.
HOLE 17 -19.3132 9.6 0.
HOLE 17 -19.7522 10.4 0.
HOLE 4 -19.3132 11.2 0. com='---'

HOLE 17 19.7522 -.8 0. com='++++'
HOLE 17 20.6309 -.8 0.
HOLE 4 21.5096 -.8 0.
HOLE 17 22.3883 -.8 0.
HOLE 17 19.3132 -1.6 0.
HOLE 4 20.1919 -1.6 0.
HOLE 17 21.0706 -1.6 0.
HOLE 17 21.9493 -1.6 0.
HOLE 4 19.7522 -2.4 0.
HOLE 17 20.6309 -2.4 0.
HOLE 17 21.5096 -2.4 0.
HOLE 4 19.3132 -3.2 0.
HOLE 17 20.1919 -3.2 0.
HOLE 17 21.0706 -3.2 0.
HOLE 4 19.7522 -4. 0.
HOLE 17 20.6309 -4. 0.
HOLE 17 21.5096 -4. 0.
HOLE 4 19.3132 -4.8 0.
HOLE 17 20.1919 -4.8 0.
HOLE 17 21.0706 -4.8 0.
HOLE 4 19.7522 -5.6 0.
HOLE 17 20.6309 -5.6 0.
HOLE 17 19.3132 -6.4 0.
HOLE 4 20.1919 -6.4 0.
HOLE 17 19.7522 -7.2 0.
HOLE 17 20.6309 -7.2 0.
HOLE 4 19.3132 -8.0 0.
HOLE 17 20.1919 -8.0 0.
HOLE 17 19.7522 -8.8 0.
HOLE 4 19.3132 -9.6 0.
HOLE 17 19.7522 -10.4 0.
HOLE 17 19.3132 -11.2 0. com='----'
HOLE 4 -19.7522 -.8 0. com='++++'
HOLE 17 -20.6309 -.8 0.
HOLE 17 -21.5096 -.8 0.
HOLE 4 -22.3883 -.8 0.
HOLE 17 -19.3132 -1.6 0.
HOLE 17 -20.1919 -1.6 0.
HOLE 4 -21.0706 -1.6 0.
HOLE 17 -21.9493 -1.6 0.
HOLE 17 -19.7522 -2.4 0.
HOLE 4 -20.6309 -2.4 0.
HOLE 17 -21.5096 -2.4 0.
HOLE 17 -19.3132 -3.2 0.
HOLE 4 -20.1919 -3.2 0.
HOLE 17 -21.0706 -3.2 0.
HOLE 17 -19.7522 -4. 0.
HOLE 4 -20.6309 -4. 0.
HOLE 17 -21.5096 -4. 0.
HOLE 17 -19.3132 -4.8 0.
HOLE 4 -20.1919 -4.8 0.
HOLE 17 -21.0706 -4.8 0.
HOLE 17 -19.7522 -5.6 0.
HOLE 4 -20.6309 -5.6 0.
HOLE 17 -19.3132 -6.4 0.
HOLE 17 -20.1919 -6.4 0.
HOLE 4 -19.7522 -7.2 0.
HOLE 17 -20.6309 -7.2 0.
HOLE 17 -19.3132 -8.0 0.
HOLE 4 -20.1919 -8.0 0.
HOLE 17 -19.7522 -8.8 0.
HOLE 17 -19.3132 -9.6 0.
HOLE 4 -19.7522 -10.4 0.
HOLE 17 -19.3132 -11.2 0.

HOLE 18 0. 0. 0.
HOLE 18 9.7 0. 0.
HOLE 18 0. 9.7 0.
HOLE 18 -9.7 0. 0.
HOLE 19 2.17 16.7 0.
HOLE 19 -2.17 16.7 0.
HOLE 19 6.52 16.7 0.
HOLE 19 -6.52 16.7 0.
HOLE 19 2.17 -16.7 0.
HOLE 19 -2.17 -16.7 0.
HOLE 19 6.52 -16.7 0.
HOLE 19 -6.52 -16.7 0.
HOLE 19  16.7 2.17 0.
HOLE 19  16.7 -2.17 0.
HOLE 19 16.7 6.52 0.
HOLE 19  16.7 -6.52 0.
HOLE 19 -16.7 2.17  0.
HOLE 19 -16.7 -2.17  0.
HOLE 19 -16.7 6.52 0.
HOLE 19 -16.7 -6.52  0.
HOLE 20 -16.7 10.86  0.
HOLE 20 16.7 -9.9914  0.
HOLE 20 16.7 10.86  0.
HOLE 20 -16.7 -9.9914  0.
HOLE 21 10.86 -16.7  0.
HOLE 21 -9.9914 16.7  0.
HOLE 21 10.86 16.7  0.
HOLE 21  -9.9914  -16.7 0.

HOLE 18 0. -9.7 0.
HOLE 18 9.7 9.7 0.
HOLE 18 -9.7 9.7 0.
HOLE 18 9.7 -9.7 0.
HOLE 18 -9.7 -9.7 0.

COM="BENCHMARK- START SOURCE SPHERE"
UNIT 10
SPHERE 2 1 2.5  ORIGIN 0. 0. 0.
GLOBAL
UNIT 8
CUBOID 2 1 292.98 -209.1 359.02 -64.02  350. -91.45
HOLE 6  0. 0. -91.44
HOLE 22 -68.962 262. 0.
HOLE 22 -120.962 262. 0.
HOLE 7 66. 148.192 74.
HOLE 7 19. 148.192 74.
HOLE 7 66. 148.192 0.
HOLE 7 19. 148.192 0.
```

```
HOLE 7 66. 148.192 148.
HOLE 7 19. 148.192 148.

'S1
HOLE 3  0. 0. 0.
HOLE 7  -23.54 14. 0.0
HOLE 7  -23.54 61. 0.0
HOLE 7  19. 101.03  0.0
HOLE 7   66. 101.03 0.0
'HOLE 7  128. 139.11  0.
'HOLE 7   175. 139.11 0.
HOLE 7  102.42 14.  0.
HOLE 7  102.42 61.  0.
HOLE 7  19. -23.54  0.
HOLE 7  66. -23.54  0.
'HOLE 7  128. -23.54  0.
'HOLE 7  175. -23.54  0.

'N1
HOLE 3  0. 217.93 0.
HOLE 7  -23.54 230.43 0.0
HOLE 7  -23.54 277.43. 0.0
HOLE 7  14. 318.54  0.0
HOLE 7   61. 318.54 0.0
'HOLE 7  118. 355.54  0.
'HOLE 7   165. 355.54 0.
HOLE 7  101.42 233.43  0.
HOLE 7  101.42 280.43  0.
HOLE 7  19. 194.47  0.
HOLE 7  66. 194.47  0.
'HOLE 7  118. 192.97  0.
'HOLE 7  165. 192.97  0.

'W1
HOLE 23  -128. 105. 0.
HOLE 7  -155.502 122. 0.0
HOLE 7  -155.502 169. 0.0
HOLE 7  -68.962 215.11  0.0
HOLE 7   -120.962 215.11 0.0
'HOLE 7  -113.962 199.11  0.
'HOLE 7   -66.962 219.11 0.
HOLE 7  -23.542 122.  0.
HOLE 7  -23.542 169.  0.
HOLE 7  -68.962 76.46  0.
HOLE 7  -120.962 76.46  0.
'HOLE 7  -113.962 36.46  0.
'HOLE 7  -66.962 56.46  0.

'e1
HOLE 23  137. 105. 0.
HOLE 7  108.502 122. 0.0
HOLE 7  108.502 169. 0.0
HOLE 7  196. 215.11  0.0
HOLE 7   146. 215.11 0.0
'HOLE 7  -113.962 199.11  0.
'HOLE 7   -66.962 219.11 0.
HOLE 7  239.46 122.  0.
HOLE 7  239.46 169.  0.
HOLE 7  196. 76.46  0.
HOLE 7  146. 76.46  0.
'HOLE 7  69 36.46  0.
'HOLE 7  -66.962 56.46  0.

'S2
HOLE 3  0. 0. 77.471
HOLE 7  -23.54 14. 73.030
HOLE 7  -23.54 61. 73.030
HOLE 7  19. 101.03  73.030
HOLE 7   66. 101.03 73.030
'HOLE 7  128. 139.11  73.03
'HOLE 7   175. 139.11 73.03
HOLE 7  102.42 14.  73.03
HOLE 7  102.42 61.  73.03
HOLE 7  19. -23.54  73.03
HOLE 7  66. -23.54  73.03
'HOLE 7  128. -23.54  73.03
'HOLE 7  175. -23.54  73.03

'N2
HOLE 3  0. 217.93 77.471
HOLE 7  -23.54 230.43 73.030
HOLE 7  -23.54 277.43. 73.030
HOLE 7  14. 318.54  73.030
HOLE 7   61. 318.54 73.030
'HOLE 7  118. 355.54  73.03
'HOLE 7   165. 355.54 73.03
HOLE 7  101.42 233.43  73.03
HOLE 7  101.42 280.43  73.03
HOLE 7  19. 194.47  73.03
HOLE 7  66. 194.47  73.03
'HOLE 7  118. 192.97  73.03
'HOLE 7  165. 192.97  73.03

'W2
HOLE 23  -128. 105. 77.471
HOLE 7  -155.502 122. 73.030
HOLE 7  -155.502 169. 73.030
HOLE 7  -68.962 215.11  73.030
HOLE 7   -120.962 215.11 73.030
'HOLE 7  -113.962 199.11  73.03
'HOLE 7   -66.962 219.11 73.03
HOLE 7  -23.542 122.  73.03
HOLE 7  -23.542 169.  73.03
HOLE 7  -68.962 76.46  73.03
HOLE 7  -120.962 76.46  73.03
'HOLE 7  -113.962 36.46  73.03
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'e2
HOLE 23  137. 105. 77.471
HOLE 7  108.502 122. 73.030
HOLE 7  108.502 169. 73.030
HOLE 7  196. 215.11  73.030
HOLE 7   146. 215.11 73.030
'HOLE 7  -113.962 199.11  73.03
'HOLE 7   -66.962 219.11 73.03
HOLE 7  239.46 122.  73.03
HOLE 7  239.46 169.  73.03
HOLE 7  196. 76.46  73.03
HOLE 7  146. 76.46  73.03
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'HOLE 7  -66.962 56.46  73.03


'S3
HOLE 3  0. 0. 154.942
HOLE 7  -23.54 14. 146.0560
HOLE 7  -23.54 61. 146.0560
HOLE 7  19. 101.03  146.0560
HOLE 7   66. 101.03 146.0560
'HOLE 7  128. 139.11  146.056
'HOLE 7   175. 139.11 146.056
HOLE 7  102.42 14.  146.056
HOLE 7  102.42 61.  146.056
HOLE 7  19. -23.54  146.056
HOLE 7  66. -23.54  146.056
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'HOLE 7  175. -23.54  146.056

'N3
HOLE 3  0. 217.93 154.942
HOLE 7  -23.54 230.43 146.0560
HOLE 7  -23.54 277.43. 146.0560
HOLE 7  14. 318.54  146.0560
HOLE 7   61. 318.54 146.0560
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'HOLE 7   165. 355.54 146.056
HOLE 7  101.42 233.43  146.056
HOLE 7  101.42 280.43  146.056
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'W3
HOLE 23  -128. 105. 154.942
HOLE 7  -155.502 122. 146.0560
HOLE 7  -155.502 169. 146.0560
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HOLE 7  -120.962 215.11 146.0560
'HOLE 7 -113.962 199.11 146.056
'HOLE 7  -66.962 219.11 146.056
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HOLE 7 -23.542 169. 146.056
HOLE 7 -68.962 76.46 146.056
HOLE 7 -120.962 76.46 146.056
'HOLE 7 -113.962 36.46 146.056
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'e3
HOLE 23 137. 105. 154.942
HOLE 7 108.502 122. 146.0560
HOLE 7 108.502 169. 146.0560
HOLE 7 196. 215.11 146.0560
HOLE 7  146. 215.11 146.0560
'HOLE 7 -113.962 199.11 146.056
'HOLE 7  -66.962 219.11 146.056
HOLE 7 239.46 122. 146.056
HOLE 7 239.46 169. 146.056
HOLE 7 196. 76.46 146.056
HOLE 7 146. 76.46 146.056
'HOLE 7 69 36.46 146.056
'HOLE 7 -66.962 56.46 146.056

'S4
HOLE 3 0. 0. 232.413
'N4
HOLE 3 0. 217.93 232.413
'W4
HOLE 23 -128. 105. 232.413
'e4
HOLE 23 137. 105. 232.413


'HOLE 10 -62 176. 59.69
'HOLE 10 244. 176. 59.69
END GEOM
READ BOUNDS XFC=MIRROR YFC=MIRROR END BOUNDS
READ START NST=6

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TFX=-23.54 TFY=61. TFZ=36. LNU=30
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TFX=102.42 TFY=14. TFZ=36. LNU=60
TFX=102.42 TFY=61. TFZ=36. LNU=70
TFX=19. TFY=-23.54 TFZ=36. LNU=80
TFX=66. TFY=-23.54 TFZ=36. LNU=90

TFX=38.7 TFY=217.93 TFZ=38.7 LNU=100
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TFX=-23.54 TFY=277.43 TFZ=36. LNU=120
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TFX=61.    TFY=318.54 TFZ=36. LNU=140
TFX=101.42 TFY=233.43 TFZ=36. LNU=150
TFX=101.42 TFY=280.43 TFZ=36. LNU=160
TFX=19. TFY=194.47 TFZ=36. LNU=170
TFX=66. TFY=194.47 TFZ=36. LNU=180

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TFX=-68.962 TFY=76.46 TFZ=36. LNU=260
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TFX=239.46 TFY=169. TFZ=36. LNU=340
TFX=196.  TFY=76.46 TFZ=36. LNU=350
TFX=146.  TFY=76.46 TFZ=36. LNU=360

'two
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TFX=101.42 TFY=233.43 TFZ=111. LNU=510
TFX=101.42 TFY=280.43 TFZ=111. LNU=520
TFX=19. TFY=194.47 TFZ=111. LNU=530
TFX=66. TFY=194.47 TFZ=111. LNU=540

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TFX=-120.962 TFY=215.11 TFZ=111. LNU=590
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TFX=-120.962 TFY=76.46 TFZ=111. LNU=630

TFX=175.735 TFY=143.735 TFZ=116.17 LNU=640
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TFX=239.46 TFY=169. TFZ=111. LNU=700
TFX=196.  TFY=76.46 TFZ=111. LNU=710
TFX=146.  TFY=76.46 TFZ=111. LNU=720


'three
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TFX=66. TFY=-23.54 TFZ=184. LNU=810

TFX=38.7 TFY=217.93 TFZ=193.642 LNU=820
TFX=-23.54 TFY=230.43 TFZ=184. LNU=830
TFX=-23.54 TFY=277.43 TFZ=184. LNU=840
TFX=14.    TFY=318.54 TFZ=184. LNU=850
TFX=61.    TFY=318.54 TFZ=184. LNU=860
TFX=101.42 TFY=233.43 TFZ=184. LNU=870
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TFX=19. TFY=194.47 TFZ=184. LNU=890
TFX=66. TFY=194.47 TFZ=184. LNU=900

TFX=-89.265 TFY=143.735 TFZ=193.642 LNU=910
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TFX=-68.962 TFY=76.46 TFZ=184. LNU=980
TFX=-120.962 TFY=76.46 TFZ=184. LNU=990

TFX=175.735 TFY=143.735 TFZ=193.642 LNU=1000
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TFX=-108.502 TFY=169. TFZ=184. LNU=1020
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TFX=146.   TFY=215.11 TFZ=184. LNU=1040
TFX=239.46 TFY=122. TFZ=184. LNU=1050
TFX=239.46 TFY=169. TFZ=184. LNU=1060
TFX=196.   TFY=76.46 TFZ=184. LNU=1070
TFX=146.   TFY=76.46 TFZ=184. LNU=1080

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'N4
TFX=38.735 TFY=256.665 TFZ=271.148 LNU=1100
'W4
TFX=-89.265 TFY=143.735 TFZ=271.148 LNU=1110
'e4
TFX=175.735 TFY=143.735 TFZ=271.148 LNU=1120

TFX=66. TFY=148.192 TFZ=112.7 LNU=1130
TFX=19. TFY=148.192 TFZ=112.7 LNU=1140
TFX=66. TFY=148.192 TFZ=38.7  LNU=1150
TFX=19. TFY=148.192 TFZ=38.7  LNU=1160
TFX=66. TFY=148.192 TFZ=186.7 LNU=1170
TFX=19. TFY=148.192 TFZ=186.7 LNU=1180

TFX=-68.96 TFY=262. TFZ=36. LNU=1200
TFX=-120.96 TFY=262. TFZ=36. LNU=1210
END START
END DATA
END
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